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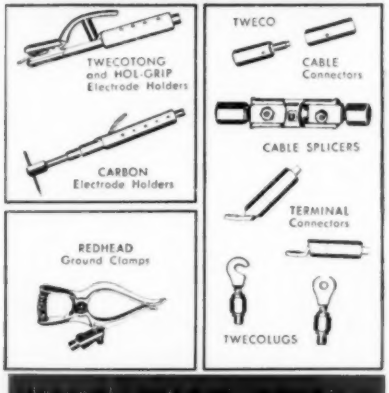

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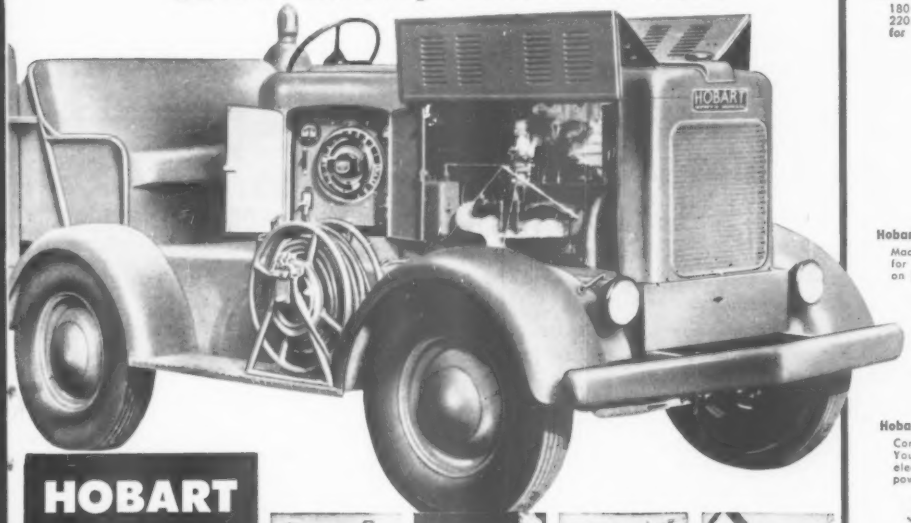

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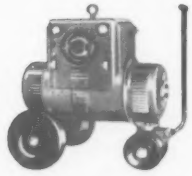

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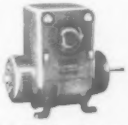

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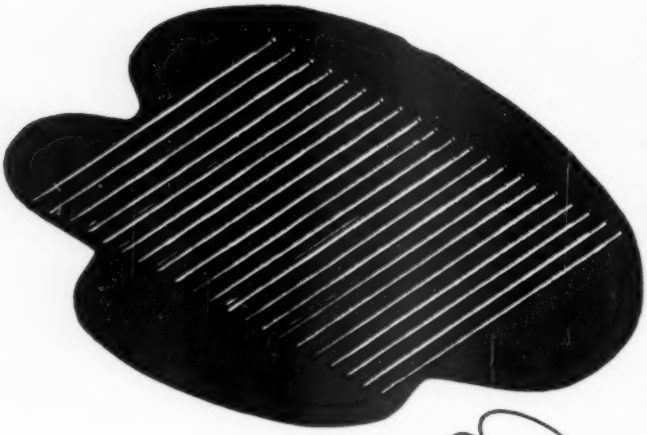

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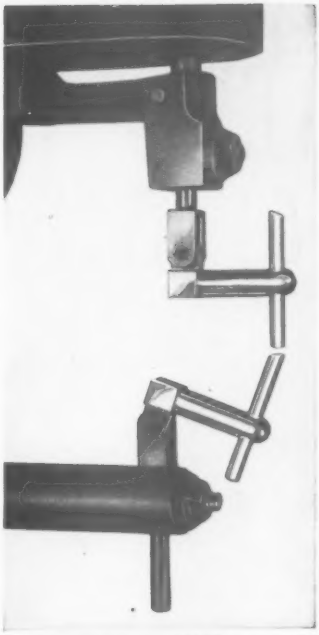

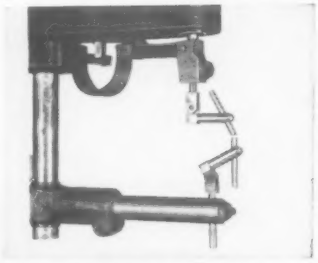

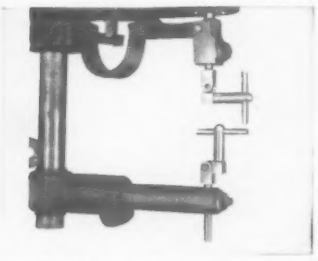

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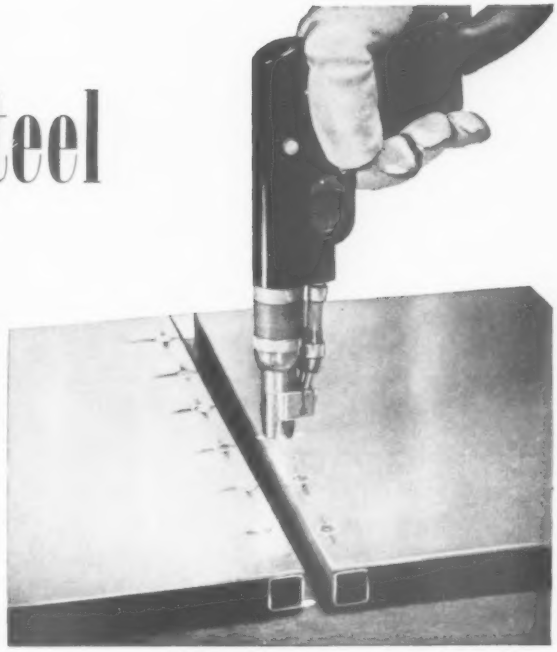

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The WELDING JOURNAL

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Investigation of Welded Ship Construction

The work of the Ship Structure Committee has attracted world-wide attention. The author briefly evaluates some of the more important pieces of research from the point of view of the ship-builder under the headings of design, fabrication and materials

by J. Lyell Wilson

I. INTRODUCTION

THE final report of the Board to Investigate the Design and Methods of Construction of Welded Steel Merchant Vessels[1,] * was published July 15, 1946. This final report of the Board has been supplemented by one technical progress report issued Mar. 1, 1948, by the Ship Structure Committee,[2,] † successor to the Board. The latter or supplementary report disclosed nothing of significant importance to justify changes in the principal findings of the final report. However, there are now and probably will continue to be doubts regarding some of the points disclosed in the report. These points are generally related to contradictions of preconceived ideas and the questioning cannot well be resolved without a thoroughly painstaking review and the publishing of related supporting data or, if restrictions continue, the repetition of appropriate testing programs.

Whether doubts are finally resolved or not there seems to be little question but that there will continue to be much interest in the work completed before the final report. There is certainly an evident desire to learn of further developments in this important field of study. Obviously, many of the problems involved are not found merely in welded ship construction. It is the purpose of this discussion therefore to give a general picture of the present status of several important phases of this work.

The following notes, like the final report, follow the outline of the major considerations in the problem as a whole, viz: Design, Fabrication and Material.

1. Design: There are two divisions of this all-important phase of the problem—(*a*) General, or over-all design of the hull girder and (*b*) Details of Construction, which may cover the broadest possible field of experimental study.

2. Fabrication: Covering methods of construction, including welding techniques, has been explored by both experimental research and analytical study. Further development in association with Design—Details of Construction is probably the most hopeful future line of study.

3. Material: Much has been done to explore the fundamental reasons for the flow and fracture of metals. Much more has been accomplished in the broad field of ascertaining the relation between composition and the physical qualities which seem to be important to resist recurrence of failures sustained.

In the following summary the findings with respect to general design are noted briefly. Those with respect to details of construction and fabrication form the major portion of this discussion and are centered primarily on details of the hatch corner tests. The reasons for concentrating upon the hatch corner tests are threefold: (*a*) the hatch corner was the most important problem, (*b*) the program of testing hatch corner specimens incorporated design, fabrication and materials and therefore seems to be the most complete project thus far undertaken and (*c*) the published data of these tests have inspired more general lay discussion than have those of any other project of study. Finally, the present status of accomplishment with regard to materials is given by way of the first year's results in the application of new hull steel plate specifications as promulgated by the American Bureau of Shipping. Briefly the data given are descriptive of the aim and apparent accomplishment of that purpose of producing hull steel plate in the various thicknesses that will be consistently less notch

J. Lyell Wilson is Research Director of the American Bureau of Shipping, New York, N. Y.

This paper was presented at the joint meeting of the New York Sections of the Society of Naval Architects and Marine Engineers and the AMERICAN WELDING SOCIETY on February 25, 1949.

* Board appointed April 1943 by the Secretary of the Navy.

† Ship Structure Committee, appointed by Secretary of the Treasury to to succeed Board after the Final Report was published. This Committee like the Board comprises representatives of: U.S.N., U.S.C.G., U.S.A. (added after original appointment and not represented on Board) U.S.M.C. and A.B.S.

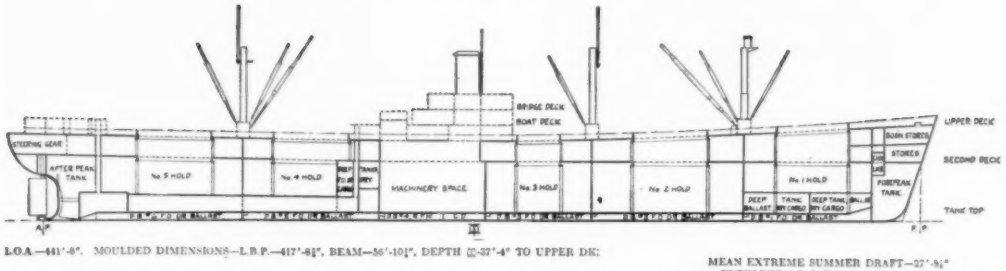

Fig. 1 Liberty ship, longitudinal profile

sensitive than that produced under former specifications. Since design refinement has already resulted in minimizing the incidence of casualty, it is confidently anticipated that the new steel will doubly check against the recurrence of fracture by limiting the effects resulting from inevitable mistakes in fabrication or workmanship.

Notch: A notch may be defined as any discontinuity. A notch means a structural discontinuity, such as is occasioned by *hatch openings, sheerstrake cutouts, foundations, vent openings, bilge keels, the abrupt termination of structural members,* etc., and *imperfections in the structure resulting from fabrication,* such as *peened over cracks, undercut welds, porosity and inclusions in welds,* and *incomplete penetration,* which leaves voids at the center of the joint.

Notch Sensitivity: Notch sensitivity may be defined as the property of a material which reflects its reluctance to absorb energy in the presence of notches and other strain inhibitors, such as low temperature and high rates of strain.

II. DESIGN—GENERAL

Classical examples of static structural tests (strain gage readings during known bending in still water) include such riveted ships as the *Wolf*,[3] *Cuyama*,[4] *Preston* and *Bruce*,[5] which formed a background of technique and resulting data. Although these, prior to the application of welding in shipbuilding, confirmed the general validity of the basic methods used for calculating the stresses from bending moments and section moduli in the main hull girder, several factors prompted the extension of similar experiments to welded ships.

There was, first, the possibility of a difference in overall behavior between riveted and welded construction. Such a possibility was accentuated by assumed differences in rigidity and known differences in geometry of riveted and welded joints. It was also discovered by photo-elastic studies that appreciable stress concentrations occurred at the hatch corners. Lastly, it was obvious that modern developments in strain gages make possible the measurement of highly localized strains and therefore the determination of unusual stress distributions that might not have been discovered in previous experiments.

Note: Resistance wire strain gages are now available in such small sizes as to include $^1/_{16}$-in. gage length.

Among the vessels thus tested were the Great Lakes ore carriers, *Cadillac, John Hutchinson, Champlain, Frank Purnell*;[6] the Liberty ship *Philip Schuyler*;[7] and the T2 tanker *Shiloh*.[8] Perhaps the most thorough and completely satisfactory experiment of this nature was that carried out by the British Admiralty Ship Welding Committee on two tankers of similar design, the *Newcombia*,[20] completely riveted, and the *Neverita*,[21] completely welded. The following are the particulars and important comparative findings quoted from these reports:

	Riveted		Welded
M/S	*Newcombia*	and	*Neverita*
460 ft. 0 in. B.P.	59 ft. 0 in. M.B.		34 ft. 0 in. M.D.

1. The stress distribution and longitudinal deflections in the two forms of construction show no major differences.
2. The local bending stresses in the particular panels examined were in general less in the riveted

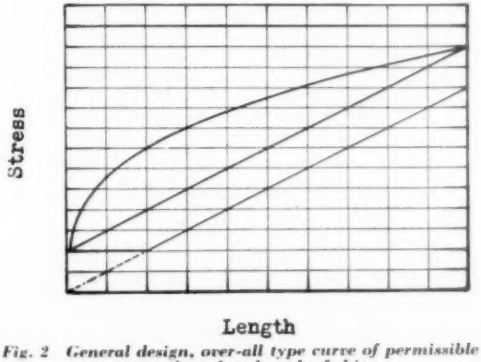

Fig. 2 General design, over-all type curve of permissible stress plotted on length of ship

ship owing to fairer plating and the stiffening influence of the riveted overlaps.

3. The stress concentrations observed around large structural discontinuities, such as hatch openings, are approximately the same for the two forms of construction. It should be recognized, however, that higher concentrations may exist at connections. An investigation of such concentration was outside the scope of these tests.

Other vessels, both old (riveted) and new (welded) have similarly been tested statically and in certain specific cases dynamically at sea. Those of importance in preliminary stress distribution studies for the hatch corner tests, include the Liberty ships, *Julian Mack*, *David Bushnell* and *George B. McFarland*. Of particular importance in the field of dynamical studies at sea is the work of Prof. George Schnadel during the sea trial trip of 1934 on the Hamburg-America Line M.S. *San Francisco*.[9] While the Schnadel tests did show that "the method of calculating the longitudinal strength of ships should be changed," it should be emphasized that the necessary change involved the use of a greater wave height for a ship in a wave hollow than for one on a crest. However the report of these tests includes the statement: "The customary methods of calculating bending moments, bending stresses, and of deflections from moments and shear are adequate for practical purposes."

For the present at least it may fairly be concluded that no fault has been found nor improvement suggested in connection with the basic analytical methods used in the general over-all design of the hull girder. Only one possible avenue for further research is that apparently left open by Prof. Schnadel in stating: "The ratio of wave heights for ships with low engine power can be derived from the present tests. For faster large ships the ratio must be increased" (M/S *San Francisco* is 430

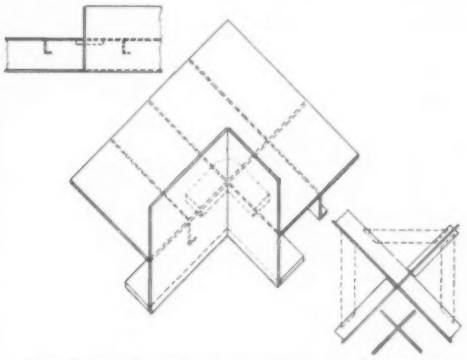

Fig. 3 Hatch corner-type specimens 1, 2, 3 and 4

Type 1—Original basic design (Specimen No. 5). Section area used, 60.5 sq. in., 100%.
Type 2—Basic design with diagonal braces added to the deck girder to hatch end beam joint. (Specimen No. 38 repeat of No. 36 rejected.) Section area used, 60.5 sq. in., 106.3%. Energy absorption at failure 182%. (Report text gives 5 and 38% increases.)
Type 3—Basic design with longitudinal girder made continuous and hatch end beam intercostal. (Specimen No. 27.) Section area used, 60.5 sq. in., 120.5%. Energy absorption at failure, 240%. (Report text gives 19.4 and 140% increases.)
Type 4—Basic design with full penetration welds. (Specimen No. 32.) Section area used, 60.5 sq. in., 125%. Energy absorption at failure, 384%. (Report text gives 24 and 280% increases.)

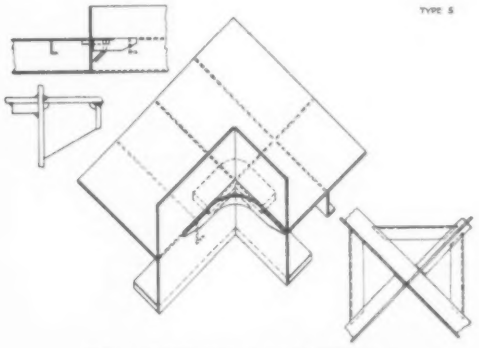

Fig. 4 Hatch corner-type Specimen 5

Type 5—Basic design with crescent insert in corner of hatch opening. Originally developed by Bureau of Ships and adopted for corrective means under designation U.S.C.G. Code 5 (Specimen No. 28). Section area used, 67.5 sq. in., 131.3%. Energy absorption at failure, 424%. (Report Text gives 30.5 and 324% increases.)

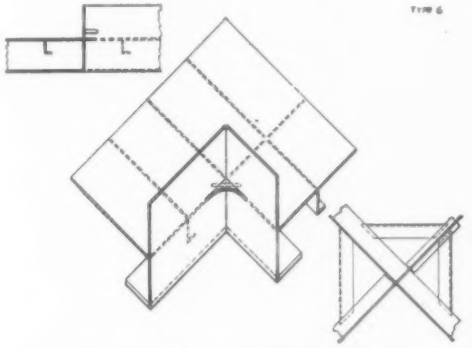

Fig. 5 Hatch corner-type Specimen 6

Type 6—Deck plate with 12-in. radius corner through slot in coaming, no doubler. (Specimen No. 29—like No. 30 without doubler.) Section area used, 56.75 sq. in., 143.3%. Energy absorption at failure, 491%. (Report Text gives 45.5 and 1539% increases.)

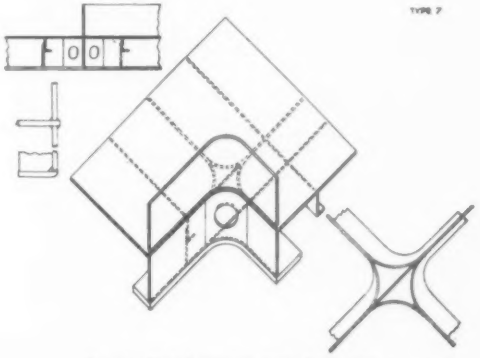

Fig. 6 Hatch corner-type Specimen 7

Type 7—Deck plate and coaming rounded at corner of hatch opening, 18 in. radius. longitudinal deck girder continuous with curved transition web connections to hatch end beam and all girder flanges rounded at cross. (Specimen No. 39, University of California, design, no doublers.) Section area used, 59.5 sq. in., 157%. Energy absorption at failure, 682%. (Report Text, not mentioned.)

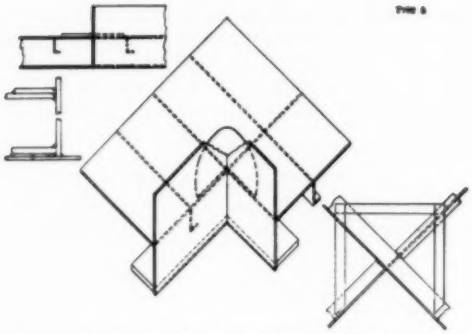

Fig. 7 Hatch corner-type Specimen 8

Type 8—Oval-shaped doubler added outside coaming at corner and connections to Coaming with Full Penetration. (Specimen No. 31, British Modification.) Section area used, 63.2 sq. in., 126.6%. Energy absorption at failure, 866%. (Report Text gives 25 and 765% increases.)

ft. long). During 1948 a realistic project to extend this data by the less expensive model experiments was proposed by the Ships Structure Subcommittee on Research to the Research Committee of the Society of Naval Architects and Marine Engineers.[10] Though less expensive a procedure and quicker than by the use of a vessel searching for appropriate weather in a single condition of loading it is still considered somewhat expensive to initiate no matter how much it needs doing.

For the present at least nothing has been disclosed which would justify any significant modification in the fundamental basis or standard by which the over-all structural strength of the hull girder is established.

III. DESIGN—DETAILS OF CONSTRUCTION

"The monolithic character of the welded ship resulting from the method of fabrication can produce joints, particularly at structural discontinuities, that have high stress concentrations and severe restraint, thereby tending to inhibit plastic flow. This condition did not exist generally in the riveted ship. The danger of high concentrations at points of structural discontinuities in

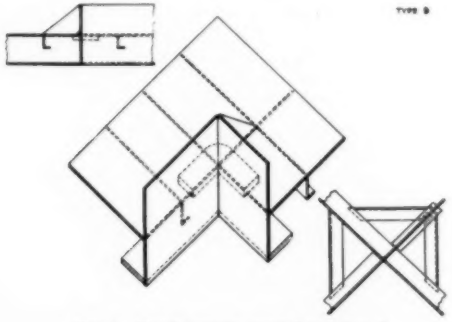

Fig. 8 Hatch corner-type Specimen 9

Type 9—Basic design with hatch side coaming extended one frame space beyond end coaming. (Specimen No. 33, side coaming, deck girder and extension bracket, One Piece.) Section area used, 74.8 sq. in., 145.4%. Energy absorption at failure, 1750%. (Report Text gives 45 and 1645% increases.)

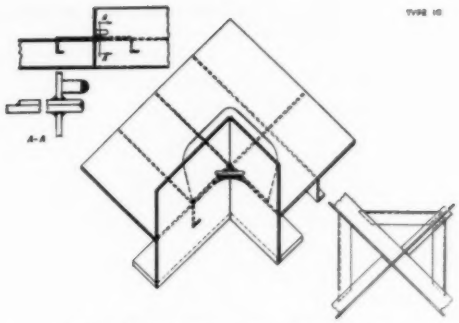

Fig. 9 Hatch corner-type Specimen 10

Type 10—Same as Specimen 6 but with doubler added and similarly radiused at corner. (Specimen No. 30, designated U.S.C.G. Code 1.) Section area used, 69.3 sq. in., 153.4%. Energy absorption at failure, 1715%. (Report Text gives 52 and 1610% increases.)

NOTE: About one-third of the fracture in the doubler of this specimen was shear which undoubtedly accounts for some of the increase in energy. The doubler in this design adds only moderately to load carrying capacity but adds about ¼ of the increased energy absorption ability.

the welded ship is further aggravated by welding usually present at such points. Welding produces a complex metallurgical condition which is supplemented by the existence of locked-in stresses and this is frequently further aggravated by additional discontinuities in the form of defects in the weld."[11]

The fact that practically all fractures were associated with such points as hatch corners, sheerstrake cutouts, defective welds, etc., amply demonstrates that stress concentrations of dangerous magnitude actually exist at structural discontinuities in welded ships. These considerations pointed to the need for determination of the magnitude of concentrations at structural discontinuities in welded ships and this was made possible by the use of newly developed short base length (less than 1 in.)

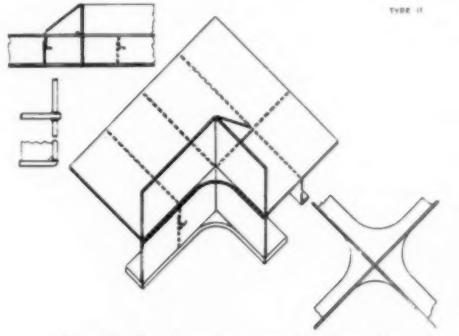

Fig. 10 Hatch corner-type Specimen 11

Type 11—Victory ship type. Deck plate separates under deck girders from hatch coaming. Deck plate and girder flanges radiused at corner of hatch opening and joint between deck girder and hatch end beam. Longitudinal girder continuous. (Specimen No. 34, A.B.S. design.) Section area used, 86.7 sq. in., 138.4%. Energy absorption at failure, 2560%. (Report Text gives 36.8 and 1990% increases.)

NOTE: Also stated in report—"The computed increase in maximum stress was only 36.8% which is somewhat less than for some of the other modifications. However, the computed stress for this specimen is probably not a fair method of comparison since it contained more metal which had to be included in the load carrying area than was the case for the other specimens, yet it seems certain that a lot of this area was actually carrying very little load. This is borne out by the load values which show that this specimen carried a load of 2,880,000 lb. which is greater than for any except Specimen 35. The energy absorption of this specimen was an increase of 1990% (should be 2460%) over that of the basic design."

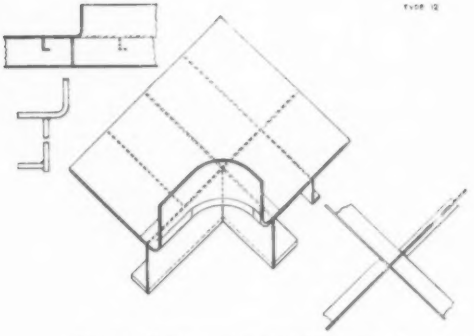

Fig. 11 Hatch corner-type Specimen 12

Type 12—The Kennedy design specimen includes a doubled-curved, hot-formed section at the corner and a rolled section at the side, both used to join the deck and hatch coaming. The hatch opening does not coincide with the lines of girder and hatch end beam but its edges are displaced by 6 in. inside of these lines. (Specimen No. 35, Kennedy design.) Section area used, 60.5 sq. in., 226%. Energy absorption at failure, 2950%.

NOTE: The extraordinary features of this type specimen include serious dimensional differences, so serious in fact as to fit the term abnormal specimen. If these were minor differences, such as the use of substandard coaming and girder depths, the effects might have little significance and in fact both specimens 33 and 34 might then also fit such a designation because for some unexplained reason these two specimens have oversize deck girders. However, Specimen No. 35 (12) departs in a significant manner from all other specimens to such a degree as to reject the results of the tests for comparison with all others.

electric strain gage. The static structural tests of the Liberty ship, *Philip Schuyler*,[7] and the T2 Tankers, *Ventura Hills*,[11] *Fort Mifflin*[12] and *Antelope Hills*,[13] included such measurements to evaluate concentrations with some of the following important results:

(*a*) Stress concentration factors of 3.0 (elastic conditions) were found on the fillet weld inside the square hatch corner at deck level. Compare with a factor of 4.0 found on hatch corner exploratory models and Liberty ship *George B. McFarland* dynamic tests. (See OSRD No. 5352 report July 21, 1945.)

(*b*) Stress concentration factors of 2.0 (elastic conditions) were measured at the inside radius of a rounded hatch corner at deck level. Compared with a factor of 3.4 found on a similar corner at sea under dynamic conditions.

(*c*) Longitudinal stresses in the hatch coaming of the order of those in the strength deck were found near the ends of the side coamings of a Liberty ship and of an *ore carrier*. (See Figs. 1 and 2.)

Most points of stress concentration result from poorly considered details on drawings. These can and have been satisfactorily corrected by the exercise of careful judgment and a proper regard for the same fundamentals as applied to machine design. Others involving defects of poor workmanship are not so readily corrected. In either case corrective measures cannot be effective without appropriate understanding and control by shipyard personnel on fabrication.

Typical of the type of design detail which does not lend itself readily to correction by such simple means was the major problem of the corner of a square hatch opening in the strength deck and especially within the midship half length. This problem was therefore studied most thoroughly and became what must be considered one of the most important research projects initiated by the Board and completed under the Interim Ship Structure Subcommittee through Bureau of Ships, Navy Department sponsorship.

Hatch Corner Tests: Part I—Fabrication

This project involved the design and testing of full-scale ship sections, by way of specimens approximating an actual section of a ship, wherein restraint to plastic flow would be provided by the inherent geometry of the structure rather than by artificially induced notches. The specimen chosen was *similar* in design to one type of hatch corner used on Liberty ships. However, as explained and underscored in an interim report, it was not intended that the specimen should be an exact duplicate of a Liberty ship hatch corner either in design or stress distribution. *"Rather, it was intended that for the most part identical plate thicknesses should be used and, to a great extent, the geometry should be the same as that of an actual Liberty ship hatch corner so that the restraint to plastic flow which resulted should be 'natural' or inherent in the design and not induced by 'artificial' notches."*

Preliminary to the final series a number of full-scale hatch corner tests were run at various temperatures on specimens of identical design (Basic) but made up of different steels. While the object of this study was primarily to correlate transition data with those of the various steels which were determined by the standard keyhole Charpy impact tests, it also resulted in unexpectedly disclosing insignificant differences in load-carrying capacity for differences in steel alone. After the ninth specimen however, energy readings showed appreciable differences between steels which tends to indicate the importance of energy absorption ability as an important quality in the base metal.

A conclusion indicated for this series in OSRD Re-

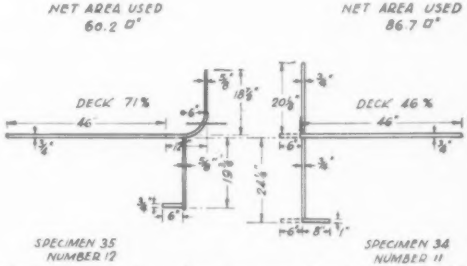

Fig. 12 Comparison of section area, Specimens 34 and 35

While it is explained in the report[12] that the rolled plate between deck and coaming resulted in the coaming being 6 in. out of line with the longitudinal and transverse girder systems, nevertheless no reason has been given for not using a narrower deck plate from the rolled section to the deck edge so that the plan of the deck and hatch *opening* would be exactly comparable with the other specimens. The result is that Specimen No. 35 represented not only, "a departure from conventional hatch design," as stated in the report but it also represented a specimen geometrically different from all other specimens tested in this project and the results of the tests on such a specimen must not be compared with those for any of the other specimens. These observations apply critically to published discussion of the tests given in reference 18 and 19 in addition to the data in the final report.[12]

port No. 6387 Serial No. M-607, stated: "In a welded structure constructed of low carbon steel, which, due to its geometry, has a high degree of restraint and a severe notch condition (as exemplified by the hatch corner specimen), *type of steel, temperature* and *type of welding electrode* has little effect upon the breaking strength."

The following summary of these data shows the significant failure strengths of this series of specimens.[14]

Table 1

Specimen No.	Type steel	Test temp., ° F.	Failure stress, psi.	Total energy in inch-pounds
1	A—as-rolled	32	24,200	At failure
2	C—as-rolled	32	23,200	...
5	C—as-rolled	68	24,000	...
10	C—as-rolled w/Murex HTS	32	23,600	180,000
9	C—stress relieved	72	29,400	...
13	C—as-rolled w/25-20 el.	32	27,700	232,000
11	B—as-rolled	32	25,600	522,000
8	B—as-rolled	66	26,100	...
3	B—normalized	32	23,500	...
4	D—normalized	32	25,900	...
12	D—normalized	72	27,800	...
6	E—as-rolled	32	23,100	...

Finally it was also concluded that, "keyhole Charpy tests over a range of temperatures appear to rate the various steels in the same order relative to transition temperature as do the full-scale hatch corner tests. However, the transition temperatures for the steels when tested as hatch corner specimens are considerably higher than for keyhole Charpy specimens. For C steel the difference in transition temperatures is 80–90° F."

Table 2 shows the principal characteristics of the steels used in these tests.

In a subsequent report,[15] July 24, 1946, results of tests on six more specimens of this preliminary series were given and the related data are shown in Table 3.

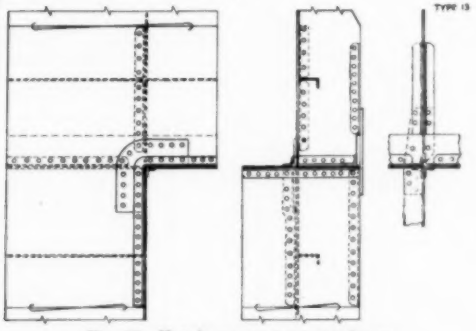

Fig. 13 Hatch corner-type specimen

Type 13—Basic design with riveting substituted for welding. (Specimens No. 16 and No. 19, riveted.)

NOTE: While data are included in this summary of notes on hatch corner tests covering the results of these so-called riveted specimens no further comments are necessary except to explain why these results should be ignored. Since this specimen is not truly representative of a riveted hatch corner and because the results of its tests have already been discussed[9] and thoroughly misunderstood it should be rejected and a proper specimen tested and given as much publicity as possible. This procedure is under consideration and may be further justified as a more satisfactory means of establishing the foundation of necessary requirement in energy absorption.

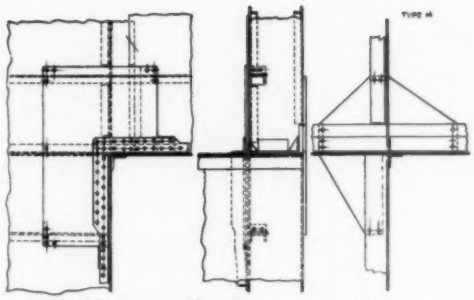

Fig. 14 Proposed hatch corner-type specimen

Type 14—Proposed riveted hatch corner specimen

NOTE: It should be emphasized that in such a series of tests on type specimens there is one condition which must hold for all specimens as being paramount. Such a condition involves adherence to a constant geometry.

It is of course necessary also to be realistic and use only such details of design as are possible in application to real ships. Therefore some consideration must be given to the size of the Liberty ship in designing a riveted hatch corner. Accordingly it should also be emphasized that just as all scantlings should be repeated in all welded corners so should appropriate riveted doublers be added as related to the plate thickness of the deck at the corner

Table 2—Project Steels

	Chemicals					
Steel	*C*	*Mn*	*Mn/C*	*P*	*S*	*Si*
A	0.23	0.47	2	0.011	0.042	0.02
B	0.15	0.76	5	0.010	0.030	0.04
C	0.24	0.49	2	0.015	0.033	...
D	0.19	0.52	2.75	0.010	0.020	0.24
E	0.23	0.39	1.67	0.019	0.032	0.008

	Physical Data			
Steel	*Yield, psi.*	*Ultimate, psi.*	*Elongation per cent in 2 in.*	*Reduction area, %*
A	35,100	61,400	49.2	58.7
B, as-rolled	31,000	56,500	53.2	66.6
B, normalized	32,200	56,900	52.0	64.0
C	37,500	66,500	45.5	56.5
D	35,900	61,300	47.1	62.3
E	31,400	57,200	49.1	59.1

NOTE: Since the Charpy keyhole notch specimens used in these tests were not oriented with respect to the notch in the manner generally accepted as proper for plate the absolute transition data are not significant.

Table 3

Specimen No.	*Type steel*	*Test temp., ° F.*	*Failure stress, psi.*	*Total energy (failure) in inch-pounds*
14	C—as-rolled	120	25,600	484,000
15	C—as-rolled w/400 °F preheat	70	32,600	1,046,000
16	C—as-rolled riveted	70	20,900	790,000
17	C—as-rolled	72	24,800	....
18	C—as-rolled w/400° F. preheat	70	32,800	1,358,000
19	C—as-rolled riveted	70	20,600	588,000

Conclusions which are significant with relation to the earlier findings quoted are:

"2. Using preheat at 400° F. is the most effective procedure yet tried both as to strength and energy absorption, being more effective than stress relief at 1000° F. for 8 hr. or than the use of 25–20 electrodes. It results in about 30% increase in maximum strength and superior performance of the welds as compared with

specimens welded in the usual manner. Preheating does not appear to influence the type of fracture."

"4. Preheating at 400° F. reduces the hardness and increases the width of the heat-affected zone and produces a somewhat different microstructure of both the weld and heat-affected zones."

"5. Postheat treatment (stress relief) at 1000° F. for 8 hr. resulted in a decreased hardness in both the heat-affected zone and the weld metal and a change in the microstructure. This treatment does not result in any change in the width of the heat-affected zone."

Finally the balance of the specimens in the preliminary series was reported under date of Oct. 23, 1946.[16] The corresponding data are shown in Table 4 which is followed with several related conclusions.

Table 4

Specimen No.	*Type steel*	*Test temp., ° F.*	*Failure stress, psi.*	*Total energy (failure) in inch-pounds*
20	B—400° preheat	75	32,400	2,758,000
21	D—400° preheat	31 and 33	33,000	952,000
			31,000	920,000
22	N—{ 25–20 elec. / 100° preheat	35	40,400	972,000
23	H—400° preheat	31	34,900	1,622,000
24	H	72–75	29,600	1,210,000
25	C	142	26,700	860,000
26	C	100	24,300	788,000

Related conclusions from final report:

"7. The only steel which produced a shear type fracture at 32° F. when built into a hatch corner type specimen was steel 'N' containing about 3½% nickel."

"8. When fabricated with preheat at 400° F. and tested at temperatures which produce a shear type fracture, steel 'B' was outstanding for its ability to absorb energy."

13. "When a steel having a considerably higher yield point (such as steel 'N') than low-carbon steel is used in a rigid and complex structure, such as a hatch corner type specimen, the energy absorption may be less than that obtained from the use of low-carbon steels fabricated with preheat. This is due to the fact that (in such higher yield strength steels) the welded joints fail before the stress has become high enough to produce any considerable amount of plastic flow in the steel. In order to obtain maximum benefit from the use of such higher strength steels in welded construction the performance of the welded joints must be improved."

"14. The substitution of riveting for welding in the hatch corner type specimens did not give as high nominal breaking stress but did result in greater energy absorption than was obtained by welding without preheat. Although cleavage type fractures were obtained in the riveted specimens, in no case did they progress farther than the second rivet hole whereas in the welded specimens cleavage fractures always resulted in complete fracture of the deck and doubler plates."

"15. The use of a highly notch resistant steel (steel 'N') welded with 25–20 electrodes did not result in as high energy absorption as was obtained with a low carbon, less notch-resistant steel, welded with type E-6020 electrode with preheat at 400° F." (See Table 5.)

Hatch Corner Tests: Part II—Design Details

This second phase of the hatch corner tests was intended to explore a series of specimens in which the design detail of the actual corner would be progressively modified more or less following the evolution of this detail as had already been applied to the Liberty ships as corrective measures. Ultimately the program was extended to include a few specimens of a type not actually used although the more idealistic, the so-called Kennedy type, simulated a type used in a very few riveted ships built many years ago.

In order to relate the resulting data with those obtained for the basic type specimen those for specimen No. 5 were chosen. It should be noted that this specimen was tested at room temperature and that it was fabricated with steel "C" as-rolled and using E-6020 electrodes without preheat or postheat treatment. It should be emphasized therefore that all subsequent specimens were similarly fabricated with steel "C" as-rolled, without preheat, and using E-6010 and E-6020 electrodes without preheat or postheat treatment.

In the following discussion of the results derived from this series of tests, much of the material is quoted verbatim from the report[17] of the investigators. Reference is also made to papers[18, 19] presented at the last two, 1947

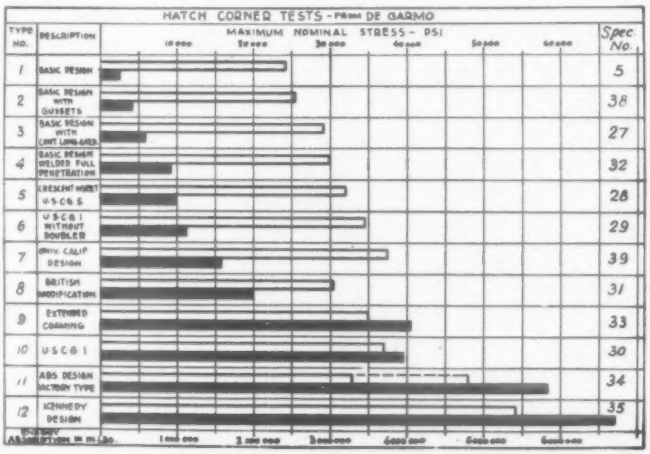
HATCH CORNER TESTS - From DE GARMO
TYPE NO.
DESCRIPTION
MAXIMUM NOMINAL STRESS - PSI
Spec. No.
1 BASIC DESIGN 5
2 BASIC DESIGN WITH GUSSETS 38
3 BASIC DESIGN WITH CONT LONG GIRD 27
4 BASIC DESIGN WELDED FULL PENETRATION 32
5 CRESCENT INSERT U.S.C.G.S 28
6 U.S.C.G. I WITHOUT DOUBLER 29
7 SHIPBLDG. CALIF DESIGN 39
8 BRITISH MODIFICATION 31
9 EXTENDED COAMING 33
10 U.S.C.G. I 30
11 ABS DESIGN FACTORY TYPE 34
12 KENNEDY DESIGN 35
ABSORPTION IN in.-Lbs.

Fig. 15 Summary chart of hatch corners on the basis of energy absorption

Solid bars show energy absorption in inch-pounds; hollow bars show maximum stress in pounds per square inch.

and 1948, annual meetings of the AMERICAN WELDING SOCIETY and published in the Society's JOURNAL.

The foregoing discussion was predicated on stress values and energy values at failure by quoting these from the reports although maximum values differing therefrom were reported in some cases. However, in reporting on values in the design series the investigators, *"felt that the stress-value which is most important is the one corresponding to maximum load,"* and, *"on the other hand the important energy value is the one which indicates all of the energy absorbed up to the point of major failure."* As a fundamental basis of comparison such a statement appears to be academic though somewhat late in being established. The statement of calculating the area of each section to determine unit stress from load (ground rules) is, however, not academic and might have been questioned had it appeared prior to publication of the final report.

These "ground rules" are: *"The nominal stress values shown in Tables 5 and 6 were computed by dividing the load by the area which supported this load. In all specimens except 33, 34, 35 and 37, this area included the deck outboard of the coaming, the longitudinal girder up to the top of the doubler, the longitudinal girder flange, and the doubler, if any. Where radii existed, as in the deck plate in specimen 29, one third of the radius was included in the width of the plate. In specimens 33, 34 and 37, having extended coamings, the transverse area of the entire longitudinal coaming was included in the load carrying area. For specimen 35* (Kennedy design) *the formed section up to two-thirds the height of the radius was included. Some of these areas were somewhat arbitrary but there did not appear to be any exact simple method which could be used."*

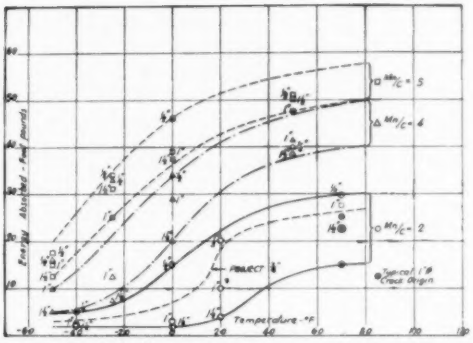

Fig. 16 Keyhole Charpy impact tests results for hull steel before 1948

Data for transition study covering samples of steel plotted as to thickness and chosen in several ratios of manganese-carbon.
NOTE: Practically no values for ½ in. thickness are found in the lower zone for Mn/C of 2. This is consistent with experience wherein casualties in welded ships seldom if ever occurred in thicknesses up to ½ in. The aim, of course, was to raise energy levels at 0° F. by increasingly refining the steel from Class A to Class C.

NOTE: Specimen 37 was a repeat of 33 and was declared invalid because of a laminated plate. Accordingly, only specimens 33, 34 and 35 are effected by this statement of fundamental basis.

Figures 3 to 15 inclusive show, by rearranging the data from the report, the sequence of improvement in energy absorption obtained by adding refinement of detail to the basic design. Included in this series, in addition to the chart summarizing the results, there are contrasting illustrations as between the riveted specimen which was tested and the proper design for such a specimen together with a contrast between sectional areas of specimens 34 and 35. (See Table 6.)

Table 5—Principal Characteristics of Additional Project Steels

Chemicals

Steel	*C*	*Mn*	*Mn/C*	*P*	*S*	*Si*	*Mo*	*Ni*	*Al*
H	0.17	0.82	4.82	0.022	0.024	0.15	0.40	...	0.056
N	0.13	0.49	3.77	0.018	0.027	0.22	...	3.34	...

Physical Data

Steel	*Yield, psi.*	*Ultimate, psi.*	*Elongation per cent in 2 in.*	*Reduction area, %*
H	37,500	63,900	44.0	67.2
N	58,000	82,000	38.0	61.5

Table 6—Summary of Selected Hatch Corner Data

Specimen sequence	*and number*	*Maximum load, lb.*	*Section area, sq. in.*	*Maximum stress, psi.*	*Relative value, %*	*Energy absorption at failure*	*Relative value, %*
1	5	1,450,000	60.5	24,000	100	230,000	100
2	38	1,550,000	60.5	25,500	106.3	417,600	182
3	27	1,745,000	60.5	28,900	120.5	552,000	240
4	32	1,815,000	60.5	30,000	125	882,000	384
5	28	2,125,000	67.5	31,500	131.3	974,000	424
6	29	1,950,000	56.75	34,400	143.3	1,132,000	491
7	39	2,240,000	59.5	37,700	157.1	1,570,000	682
8	31	1,920,000	63.2	30,400	126.6	1,990,000	866
9	33	2,610,000	74.8	34,900	145.4	4,024,000	1750
10	30	2,550,000	69.3	36,800	153.4	3,938,000	1715
11	34	2,880,000	86.7	33,200	138.4	5,800,000	2560
12	35	3,265,000	60.5	54,100	226	6,786,000	2950

(10) Chemical Composition—Ladle Analysis.—(*a*) Except as specified in Paragraph (*b*) the material shall conform to the requirements of Class A as to chemical composition.

(*b*) Plates over $^1/_2$ and up to 3 in., inclusive, in thickness shall conform to the requirements of Class B as to Chemical composition. Plates over 1 in. in thickness shall conform to the requirements of Class C as to chemical composition.

	Class A	Class B	Class* C
Carbon, max., %	....	0.23	0.25
Manganese, %	....	0.60–0.90	0.60–0.90
Phosphorus, max., %	0.04	0.04	0.04
Sulphur, max., %	0.05	0.05	0.05
Silicon, %	....	....	0.15–0.30

*NOTE: Plate steels produced to the requirements of Class C shall be made with fine grain practice.

Fig. 17 Chemical composition specifications—1948 American Bureau of Shipping rules covering hull steel plates and shapes

IV. MATERIALS

Although the modification of design details with regard to expediency measures used to cure vessels already built and to refinement of design in vessels to be built has resulted in effectively minimizing the incidence of fractures, the problem was not completely solved. It should be recalled that the earliest measures of application during 1943 and of revision beginning 1944 have already given many more satisfactory service months statistically than were possible with the service months forming the basis of the incidence of fracture. However, the possibility of notch effect from sources other than design, such as flaws or defects of workmanship in welding, not readily detected, demands some consideration of the notch resistant quality of hull steel plate.

Until the appointment of the Board, most engineers were content to think in terms of impact energy as an index for notch resistant quality. This was usually determined by way of the impact testing of a standard keyhole Charpy specimen or alternatively a similar specimen with a V notch. The usually accepted standard requirement was an energy value of something like 15 ft.-lb. at room temperature or at the intended operating temperature.

Among other studies early in these wartime investigations were many efforts to reconcile the results of Charpy tests with comparable data from hatch corner studies and those of wide plate specimens. In the case of wide plate tests which showed strength values from about 45,000 psi. for 12-in. wide specimens decreasing to yield point value for 72-in. wide specimens.

In any case a tremendous activity was initiated to find some method or sample for testing which would give results more accurately discriminating the various steels of the hatch corner and wide plate tests than did the familiar Charpy test. However, the results in most cases have relatively as much disadvantage with respect to such factors as scatter, real significance of transition temperature and the interpretation of energy criteria.

Actually transition temperature appears to be of far less importance than energy absorption level especially in the light of the results of the hatch corner specimen tests. That is the reason for showing the results on the basis of relative energy instead of nominal maximum stress values.

Concurrent with these investigations into the characteristics of hull steel, the steel companies were collaborating with the American Bureau of Shipping in the matter of tracing differences in certain steels which seemed free from trouble as compared with those showing the greatest incidence of trouble. Through collaboration with British investigators, especially those active in the Admiralty Ship Welding Committee it was possible to not only exchange data but also to exchange steel, both slab and rolled-plate, for thorough exploration and comparison. (Fig. 16)

As a result of these studies, the Committees of the American Bureau of Shipping approved the adoption of new steel specifications based on a philosophy completely different from that being followed by the majority of investigators who are searching for a new test and criterion for a characteristic which cannot even yet be defined with precision even if it were inherently constant.

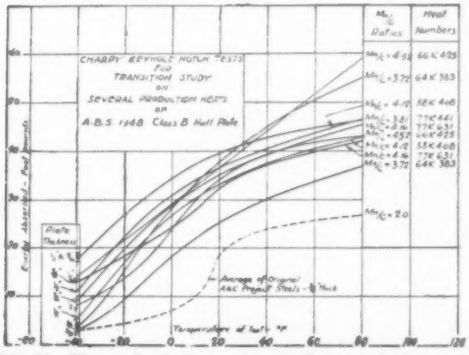

Fig. 18 Charpy keyhole notch tests for transition study on several production heats of A.B.S. 1948 Class B hull steel plate

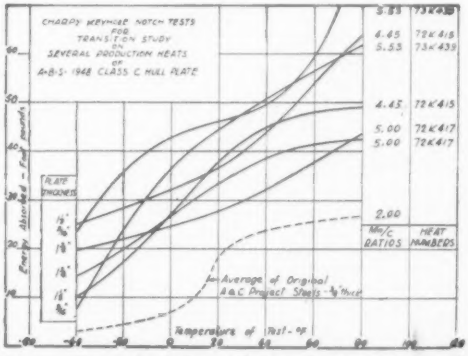

Fig. 19 Charpy keyhole notch tests for transition study on several production heats of A.B.S. 1948 Class C hull steel plate

It was found, for example, that notch toughness for material from the same heat decreases generally as thickness increases, and that more or less without regard to the type of steel within the reasonable limits of composition for low-carbon hull steel. The most important factor discovered was the relationship between manganese-carbon ratio and notch toughness. So pronounced was this factor that it became one of the significant factors in evaluating results from most other investigations.

Accordingly the American Bureau of Shipping added chemical requirements to the usual previous physical requirements. These requirements were added by way of three classes A, B and C, dividing classes at the two thickness levels, 1/2 and 1 in. which eliminates the problem of segregation for specific purposes. Figures 17 to 19 inclusive show the specifications and results being obtained at present under these specifications.

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(*Continued on page 363*)

Railroad Car Welding

New applications of submerged melt welding are covered and interesting applications of inert-gas welding to stainless steel and non-ferrous metal welding in railroad car welding are described

by C. R. Strutz

WELDING by many processes—oxyacetylene, electric arc, spot, resistance and pressure—has played an increasingly important part in the production of railroad equipment in the last decade. Two processes are still fairly new but, through recent industrial expansion, have been called into use on an increasing scale. These are the submerged melt and the inert-gas-shielded electric-welding processes generally known as Unionmelt and Heliarc welding. Both of these are characterized by speed and economy of production and the high quality of the weld metal deposited. These qualities are responsible for the wide use of the processes as fabricating methods in the construction of freight and passenger cars and particularly in the production of new designs of cars and car equipment. It is our purpose to describe at length some of the applications of these processes with the hope that the methods and equipment shown will suggest new uses, not only in the railroad field but also in the many related fields of industry.

Although Unionmelt welding, frequently referred to as submerged-melt welding, has been used for some time for the fabrication of railroad car tanks, passenger car underframes and side panels, the last two applications of the process have been considerably widened in the past two years. Within this same period, the Heliarc inert gas-shielded arc process has been accepted as the major tool for welding aluminum and Everdur car tanks and other structures.

The acceptance by the railroads of welded construction over riveted construction has had a far-reaching effect on equipment manufacturers. The change has made possible the abandonment of much heavy punching and riveting equipment and required the installation of welding machines, fabricating jigs and testing equipment. Concurrently, shop flow sheets, fabrication methods and floor plans were studied to assure greater economies in manufacture.

The peculiar advantages to the railroads of welded over riveted construction may be defined as follows:

1. Elimination of possibility of leaks and corrosion due to the high quality of welded joints. In riveted boilers there may be leakage and caustic embrittlement and age hardening about the rivets. In riveted tank cars, leakage and contamination of the lading from previous ladings may occur. In box cars, gondolas and hopper cars, there is likely to be corrosion at ledges and between the faying surfaces. All of these difficulties are overcome by welded design.

2. Welded design usually results in a lighter dead load by reason of greater joint efficiency and elimination of butts, straps and rivets thus permitting greater pay loads with the same motive power. A study of the weight saving to be realized by welding over riveting in a hopper car revealed the following: The car had an estimated light weight of 42,100 lb., a capacity of 2051 cu. ft. level full, and 2316 cu. ft. capacity if loaded with a 10-in. average heap. There were 14 stakes of 0.390 in. thickness per car secured with two hundred and ninety-two $^{5}/_{8}$-in. rivets. The $^{3}/_{16}$-in. thick sides were secured with two hundred and four $^{5}/_{8}$-in. rivets at the top chord and side sill. The elimination of the rivets and flanges on the sides alone resulted in a saving of 664 lb. per car with the elimination of 496 rivets and the associated hole punching and driving.

SUBMERGED-MELT WELDING

Submerged-melt welding is generally applied as a completely automatic process wherein a bare rod is fed from a reel into the welding zone by means of a rod-feed motor. Welding current is introduced into the rod as it slides between contact jaws or through a nozzle. A granulated welding composition covers the end of the rod and the weld. Part of the composition melts in the welding heat and submerges the fluid weld metal. This makes possible the use of high current densities, although current densities of 3000 to 10,000 amp. per square inch of electrode cross section are normally used in ordinary shielded metal arc welding; in Unionmelt welding, current densities up to 40,000 amp. per square inch and more are commonly used. This is an important factor in the achievement of the deep penetra-

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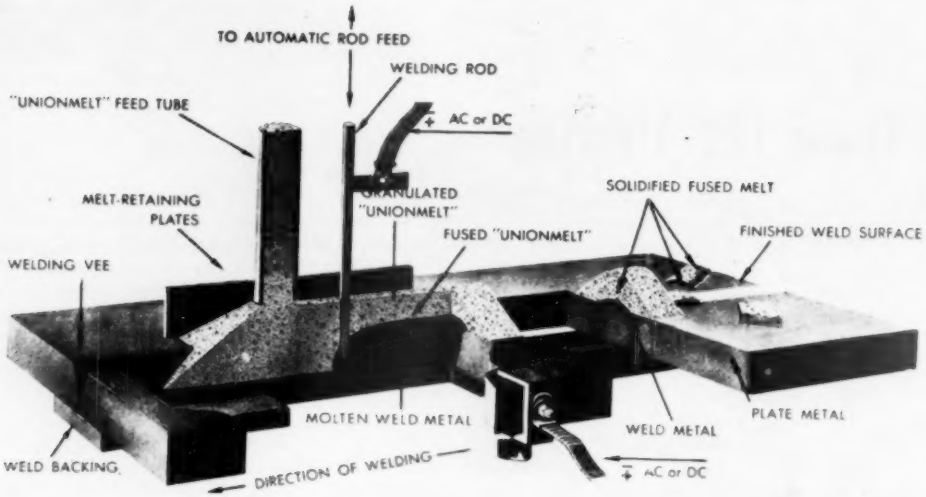

Fig. 1 The submerged-melt welding process

tion, high welding speeds and high quality of these welds. A schematic drawing of the process in operation is shown in Fig. 1. Butt joints are generally made in one or two passes in usual thicknesses of plate and multipass procedures may be used for welding joints of any thickness. Less welding rod is actually used per foot of weld than for manual welding because the high heat and consequent melting of considerable width of parent metal makes possible close joint fit-up and small size of the weld vee. The weld is produced without spatter and the finished weld surface is smooth, clean and uniform. Distortion is minimized because of the manner of heat application. Wherever welded joints are permitted, submerged-melt and inert-gas-shielded arc welds fully meet the requirements of all codes and specifications relating to railroad structure.

Several types of welding heads are made in different sizes for various ranges of work and various purposes. The head most widely applicable to railroad use at present is the Unionmelt "UE" type with electronic control. This head, shown in Fig. 2, together with its associated control panel offers the most precise control and widest operating range, welding materials as thick as $1^1/_4$-in. plate which can be butt welded with one pass using $^5/_{16}$-in. welding rod at 2000 amp. as well as material as light as 18 gage, B.W.G. (0.049 in.).

Several granular compositions and welding rods for the Unionmelt process are available, making it possible to weld carbon-alloy and stainless steels, nickel, Everdur, Cupro and Monel. Butt joints, lap joints, positioned and nonpositioned fillets, through welds and rivet welds can be welded. Welding is done with either alternating or direct current and various methods are used to move the welding head along the seam. Some

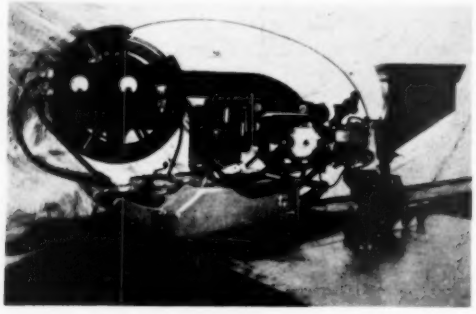

Fig. 2 Unionmelt "UE" welding head

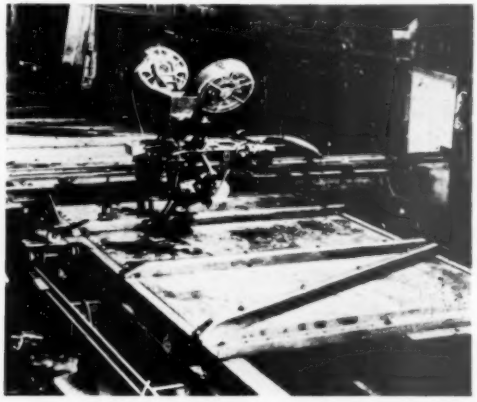

Fig. 3 Dual head for welding stakes to side sheet of a Hopper Car

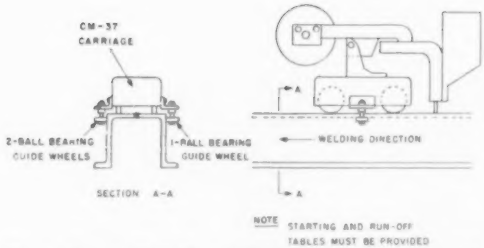

Fig. 4 Center sill welding with carriage mounted on work

typical installations are shown in the accompanying photographs.

Two welding heads, as shown in Fig. 3, are mounted on one carriage for simultaneously fillet welding both sides of the stakes of hopper cars to the side sheet. The track is pivoted so that the diagonal post at each end of the car can also be welded. Excellent welds can be obtained at speeds of around 40 in. per minute while speeds as high as 80 in. per minute have been obtained in certain production operations.

For operation in a small shop a simpler installation of the welding head is shown in Fig. 4. Here the unit operates on a center sill using it as a track. A cross section of a center sill fixture, which uses refractory material in place of a copper bar weld backing, is shown in Fig. 5. This type of fixture is more economical to build than those requiring copper backing. The use of the refractory material makes it unnecessary to pay such close attention to fit-up and also compensates for mill tolerance of center sill sections.

Slot welds are used in assembling the center brace and draft gear into center sills. These welds are made through slots previously cut with an oxyacetylene blowpipe. Figure 6 shows the slot welds as well as the application of the body bolster cover plate to the center sill of a freight car.

Rivet or plug welds are made through previously punched holes as shown in Fig. 7. This type of weld is used in various places in assembling the parts of a car, particularly in joining heavier members to the under frame and center sill of the car.

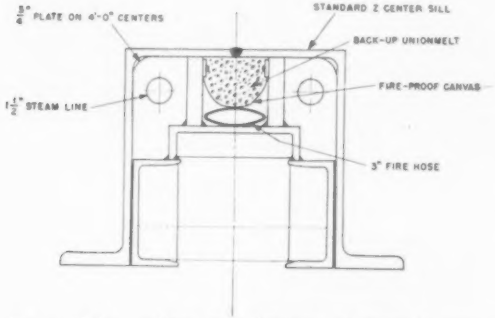

Fig. 5 Z-bar welding with back-up of granular composition

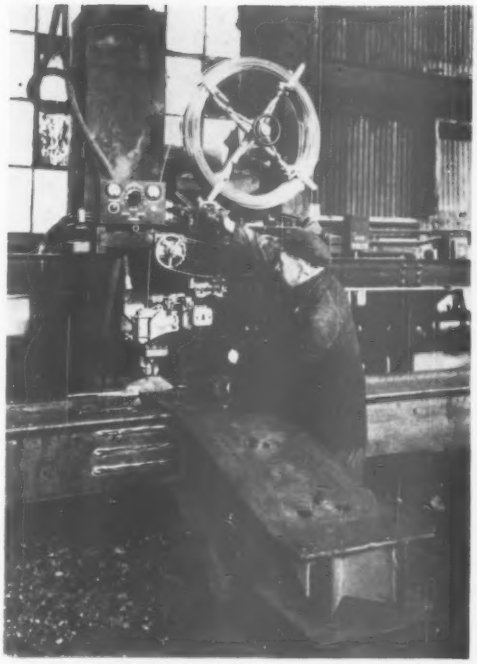

Fig. 6 Application of body-bolster cover plate and illustration of use of slot welds

Fig. 7 Plug welds are made through holes punched in the plate

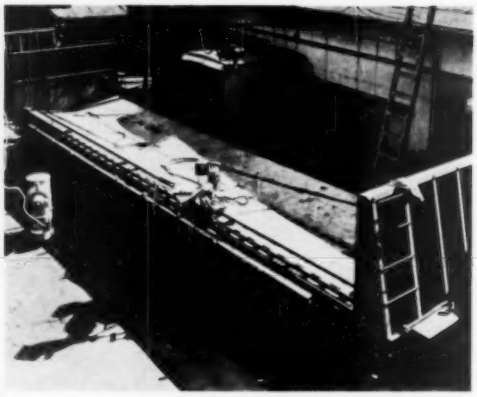

Fig. 8 Welding new floor sheets of pulpwood car. Welding machine guided by track mounted on work

An interesting example of car rebuilding is shown in Fig. 8. New floor sheets are being applied to cars used in pulpwood service. The center sills which were very old and corroded were flame cleaned before the new floor sheets were installed. The entire assembly of floor sheets and side angles was fitted and tack welded. Unionmelt welding was then used for the finish welds. The portable welding machine was guided by a track placed directly on the floor sheets. Details of the welds are shown in the sketch (Fig. 9) and the associated data on Table 1.

Table 1—Applying New Floor Plates to Old Pulpwood Cars

	Weld Nos. 1 and 2	*Weld Nos. 3 and 4*	*Weld Nos. 5 and 6*
Current, amp.	600	650	550
Voltage	30–31	30–31	25–26
Welding speed	16–18	31–32	16–20
Unionmelt	No. 90, 12 x 200	No. 90, 12 x 200	No. 90, 12 x 200
Electrode	No. 36, 5/16 in.	No. 36, 5/16 in.	No. 36, 5/16 in.
Width of weld	5/8	5/8	1/2-in. fillet
Height of weld	7/16	1/2-in. fillet	
Melt burden	3/4	1/2	3/4
Grade of steel	OHS	OHS	OHS
Angle of rod	Vertical	12° trail	20° trail 30° longitudinal

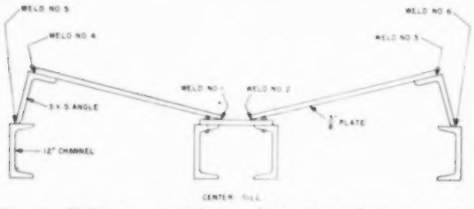

Fig. 9 Welds required for applying floor sheets to pulpwood cars

The latest development in submerged-melt welding is the portable hand welder as shown in Fig. 10. In almost all of the previous applications the travel of the welding head has been accomplished by mechanical means. With the hand welder the nozzle is moved along the seam manually. This unit makes it possible to do miscellaneous jobs such as repairs on joints normally inaccessible for automatic welding. The speed of operation with the flexible welder is much greater than that of other kinds of manual welding.

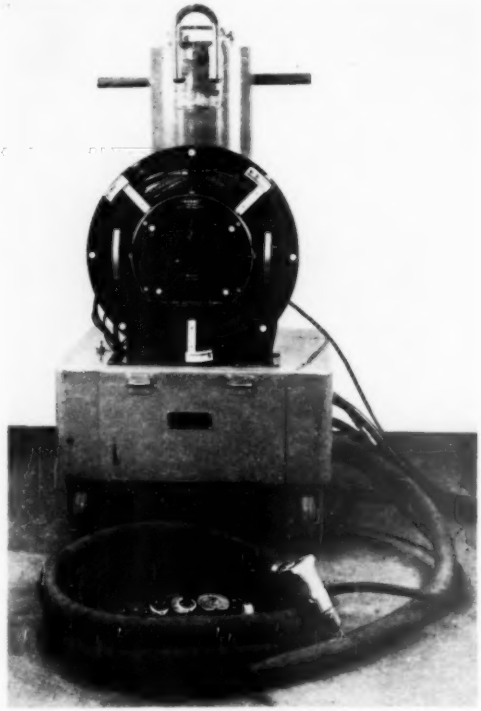

Fig. 10 Manually guided welding with the Unionmelt flexible welder

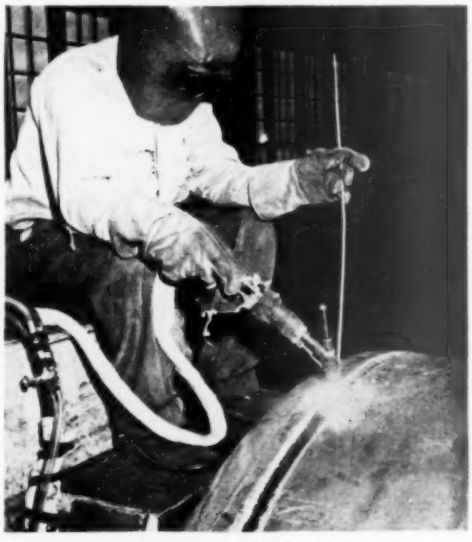

Fig. 11 Welding an aluminum car tank

INERT-GAS-SHIELDED WELDING

The second part of this paper concerns the inert-gas-shielded arc process. In this process the arc is formed between a tungsten electrode and the work. The electrode, arc and fused metal are surrounded by an inert, monatomic gas (usually argon) and thereby protected from atmospheric contamination. The tungsten electrode is virtually nonconsumable, since heat is conducted from it by a water-cooled holder and oxidation is prevented by the shielding gas.

A cup surrounding the tungsten electrode confines the shielding gas to the welding zone and keeps it from mixing with the air until its work is done. The inert-gas-shielded arc torch is light and easily manipulated. Two hoses and a water-cooled power cable supply the shielding gas, cooling water and electric current for the operation of the torch.

Fig. 12 Seal welding an icebox cover

When welding sheet thicknesses of metal, the joint is frequently designed so that the weld is made without addition of welding rod. For heavier work, welding rod is usually required and this is added manually. By this process, stainless steels and nonferrous metals are readily welded without flux. The elimination of flux, the smoothness of the deposit and the speed with which it is made are the chief advantages of the inert-gas-shielded electric-welding process. This process is being used to a considerable extent in the fabrication of railroad equipment, chiefly in the fabrication of aluminum car tanks. Other materials such as stainless steel, Everdur and Monel products are also fabricated. Recently the process has been extended to railroad shops for use on cars, locomotives and miscellaneous articles such as furniture and car accessories.

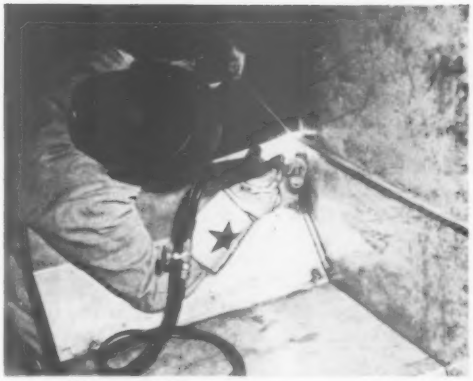

Fig. 13 Stainless steel air-conditioning condenser tank fabricated by inert-gas-shielded arc welding

Aluminum tanks of 2S or 3S used for the transportation of nonregulatory commodities are designed to AAR specifications for fusion welding by the gas-shielded process. Figure 11 shows the welding of such a tank. The barrel of the tank consists of a heavy bottom sheet and two lighter top sheets. Generally $^{5}/_{8}$-in. plate is used for the bottom and $^{3}/_{8}$-in. plate for the top sheet. They are prepared with a 60°-vee, $^{1}/_{8}$-in. nose and fitted with the vee inside. Welding is done manually using approximately 400 amp. on a $^{1}/_{4}$-in. diameter tungsten electrode. The power is supplied from a 1000-amp. transformer on which a high-frequency current is superimposed. The argon-shielding gas is delivered at approximately 16 liters per minute, and controlled to lower pressure at the welding station. Filler rod of $^{1}/_{4}$-in. diameter is fed into the weld pool manually. The outside of the joint is then prepared with a vee gouge about $^{3}/_{16}$-in. deep, following which the finishing pass is deposited.

Fig. 14 Cast aluminum Westinghouse brake cylinder repaired by inert-gas-shielded process

The welds in these aluminum tanks are generally completely X-rayed and they pass without difficulty the most stringent X-ray requirements which we are accustomed to apply to steel welds.

Inert-gas-shielded electric welding is particularly adaptable to such work as the fabrication, installation and repair of Pullman, coach and dining car equipment made of 16-gage stainless steel. In Fig. 12, the operator is seal welding the corners of in icebox cover. No welding rod is used in this application. Previously the joints were spot welded and soft soldered. A wooden insert was used to eliminate the vibration which invariably caused broken joints. A permanent sanitary joint is produced by inert-gas-shielded welding and the lid is now much lighter because the wooden filler has been eliminated.

The welding of a coach air-conditioning condenser tank is shown in Fig. 13. These tanks are made of 12-gage stainless steel which will probably replace Everdur tanks of the same type. Butt, fillet and flanged joints were welded using $^1/_8$-in. welding rod with 115 amp. of alternating current. A $^1/_8$-in. tungsten electrode was used in the torch.

A damaged 14-in. Westinghouse brake cylinder which has been repaired is shown in Fig. 14. This part, made of cast aluminum, was broken into seven pieces and economically welded using a $^3/_{16}$-in. electrode and 250 amp. alternating current.

Ladies' vanity chairs and lounge chairs on passenger cars are currently being fabricated by this process. The framework of these chairs is made of $^3/_4$-in. square aluminum tubing. Figure 15 shows an operator welding the frames of these chairs. Each weld requires two minutes. Welding currents used are from 150 to 175 amp. with an argon flow of 10 liters per minute. The complete framework is shown in Fig. 16.

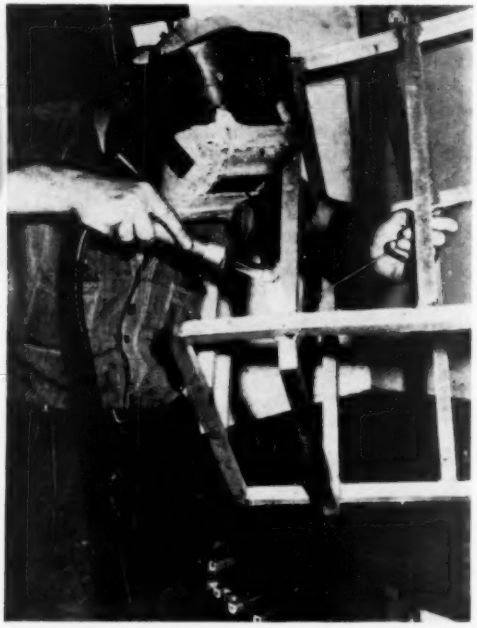

Fig. 15 Aluminum frame of ladies' vanity chair made of $^3/_4$-in. square tubing fabricated by inert-gas-shielded arc process

Fig. 16 Complete frame of ladies' vanity chair

An aluminum mirror frame is fabricated in much the same manner as door frames. Figure 17 shows jig for clamping the parts, the frame as welded and the completely finished frame. Other items fabricated or repaired by this process include vestibule light receptacles, steam table doors, garbage landing tables and chutes and sinks. Aluminum decorative grill work made of extruded tubing and channel is also economically welded by this process. There are, of course, many other possible applications which have not as yet been investigated.

In the last four or five years the submerged melt process has been used extensively in the construction of tens of thousands of cars. Results have proved this method of fabrication is highly successful. There is no doubt that further use of the process will radically change the methods of car construction.

The method of inert-gas-shielded arc welding is comparatively new, having been introduced into the railroad field only within the last year and a half. The phenomenal growth in the use of this process in this relatively short time gives every indication of very wide acceptance and greater variety of applications of this process for the future.

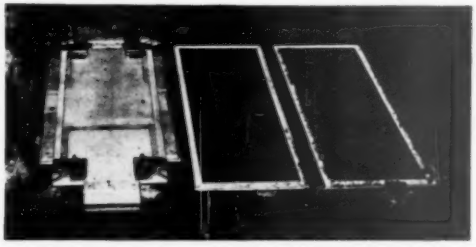

Fig. 17 Steps in the fabrication of aluminum mirror frames for passenger car use

The Metallurgy of Arc Welding in Steel

An article based on a series of lectures on the fundamentals of metallurgy of arc welding in steel given during the Annual Meeting of the American Welding Society, Philadelphia, October 1948, under the auspices of the Educational Committee of the Society

by Prof. R. D. Stout

INTRODUCTION

THE process of arc welding in steel is apt to be regarded by the welding operator as a fairly simple physical operation in which two pieces of steel are joined by a bond of fused metal. From his own experience, nevertheless, the operator may realize that some steels are more difficult to weld than others, that cracking or warping may complicate his job and that welding may change the properties of the steel considerably.

To the metallurgist, the same welding process represents a concentrated example of almost every metallurgical phenomenon that occurs in steel. Because of his preoccupation with the problems of welding, he may be at the point of wondering why the process works at all. At any rate, the welding of steel comprises a highly fascinating field for metallurgical investigation.

This paper and the lectures on which it is based are intended to present to the reader some of the basic metallurgical principles involved in arc welding. It is hoped that they may help him to recognize how the metallurgical phenomena act to produce the effects he has already observed in the shop. It may be that he will thereby be able to appreciate the steps necessary to avoid or remedy troubles that come up in the welding operation.

PHASES OF METALLURGY IN ARC WELDING

In the production of a weldment and its use in service, one can find an application of nearly all the phases of interest included in the metallurgy of steel. To state this concretely, a list can be drawn of the processes involved:

1. Fusion—steel making
2. Casting
3. Hot and cold forming
4. Heat treatment
5. Physical properties vs. metallurgical structure

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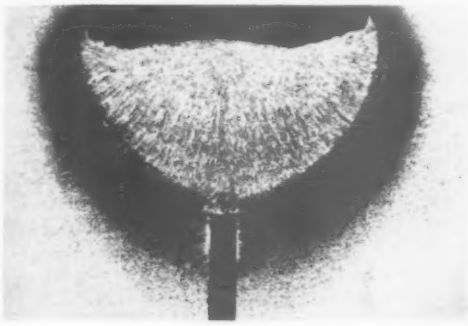


Fig. 1 Cross section of the weld zone, 5 diameters Nital etch

In Fig. 1 is shown a cross section of a first-pass weld, which has been polished and etched with acid to show the zone surrounding the weld. The oval area or nugget at the center represents the fused metal which has been obtained under conditions similar to those obtained in a steel-making furnace. The freezing of this nugget has taken place under circumstances which are present in the making of a chill casting. The cooling of the heated metal has led to shrinking and deforming of the metal just as though it were being pressed or pulled in a machine. The darkened zone surrounding the weld nugget indicates the extent to which the base plate has been heat treated by the heating and cooling cycle of the welding. This heat treatment may harden or soften the steel, and the changes in the steel's inner structure may cause a reduction in ductility and toughness in the steel.

In succeeding sections, each of these metallurgical phases will be discussed from two viewpoints: (1) what elementary principles of metallurgy are involved, and (2) how they pertain to welding.

THE FUSION PROCESS

The production of a weld by means of the electric arc is essentially a steel-making process. The electrode and plate metal supply the iron, which is melted down by the heat of the arc. Chemical agents in the form of

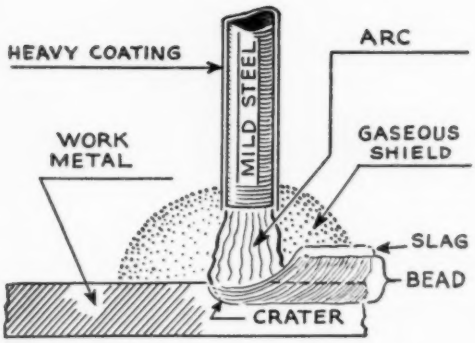


Fig. 2 Diagram of the shielded metallic arc

fluxes and reducing agents are furnished by the electrode coating to protect and purify the molten metal. These ingredients are necessary if a sound weld, free from impurities and gases, is to result.

In Fig. 2, a diagram of the arc zone serves to illustrate the features present during welding. The arc provides heat for melting the metal, and for either melting or vaporizing the coating. The arc stream and the pool of molten metal at its foot are enclosed in a gaseous shield which tends to exclude oxygen and nitrogen of the air. Figure 3 is a similar sketch for the case of the slag-forming electrode, which is designed to supply a blanket of slag over the freezing metal as a protection against the air.

In either of these operations the metal is fused and heated to a temperature where it becomes strongly reactive. The iron is readily oxidized by oxygen, H_2O or CO_2. It has a strong solubility for gases such as H_2 and N_2. If elements such as silicon, titanium, aluminum or manganese are furnished to scavenge the oxygen and thus protect the iron, they necessarily form oxides in the process. These oxides formed in the metal may not have time to float clear of the metal and, instead, are entrapped as inclusions. As in steel-making, the object is to produce a weld metal free from gases and having as little trapped oxide or slag as possible, so that a clean, sound steel can be obtained.

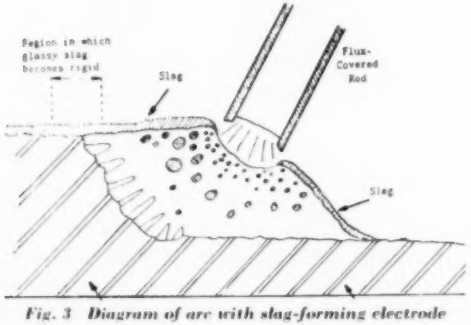


Fig. 3 Diagram of arc with slag-forming electrode

Why are N_2, H_2 and O_2 so undesirable in the weld metal? Nitrogen has been found to embrittle steel, especially at low temperatures. Hydrogen not only may cause fisheyes in the weld metal, but also gives rise to base metal cracking (see Fig. 4), as will be described later. Oxygen is responsible for blowholes or porosity, as in Fig. 5, and results in dirty and low-quality steel welds.

The electrode coatings, therefore, are designed to keep out undesirable elements by setting up a barrier against them and also by actively scavenging the metal if any of them have been picked up by the metal.

Fig. 4 Base metal crack shown by etching and magnaflux, 5 diameters. Nital etch

Fig. 5 Wormhole porosity in weld metal

WELD SOLIDIFICATION

Once molten metal has been produced in the joint, its behavior during subsequent cooling and freezing will be similar to a steel casting poured into a metal mold. Therefore, to understand this part of the welding process, it will be necessary to consider how a metal freezes, how alloying elements affect its freezing, and what kind of solid structures form in metals when they solidify.

Liquid State

When metal is molten, its atoms are free to move about at random. While they are attracted to one another somewhat, as is shown by surface tension and

viscosity properties, they have sufficient mobility to allow the liquid to conform to whatever shape the containing vessel may have. In the liquid state, therefore, metals do not display any regular internal arrangement of the atoms. If the metal liquid contains more than one metal, it is, in effect, a solution, in which the several types of atoms are mixed indiscriminately. Thus, liquid steel is a solution of carbon, manganese and other alloys in molten iron.

Solid State

If a molten metal is allowed to cool, a temperature is reached where it can no longer remain completely liquid and where it therefore begins to solidify. In losing temperature, the metal atoms lose energy, and with it, the freedom of movement or mobility displayed in the liquid state. What happens during solidification, then, is that the attractive forces between atoms overcome their mobility and the atoms begin to arrange themselves in a regular pattern. The intensity of the attractive forces will be reflected by the strength and rigidity of the solid metal. These regularly arranged aggregates are called crystals, and the geometric arrangement is called a crystal lattice.

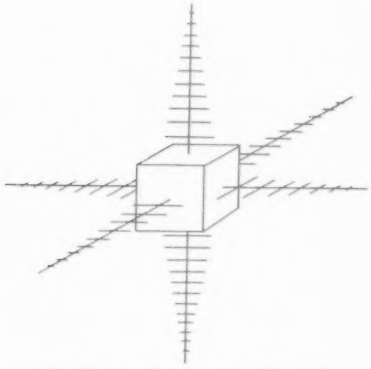


Fig. 6 Dendritic growth of crystal

Freezing must commence somewhere, and it will tend to be at some point where the temperature and the accidental groupings of atoms favor it. Such starting points are called nuclei and are essentially small crystals. Once a nucleus has formed, additional atoms can attach themselves to it, causing the nucleus to grow in size. The growth of the crystal tends to take place in certain preferred directions which are directly related to the internal arrangement of the atoms which is taking place. In Fig. 6, a sketch is presented to illustrate this point. The growth of the crystal is along axes which here are shown to be at right angles to one another. The crystal may acquire a series of interlocking arms or branches and is then designated as being dendritic, treelike. Ordinarily, freezing begins with the formation of many nuclei,

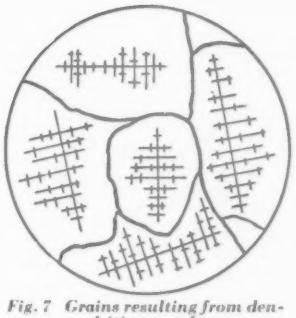


Fig. 7 Grains resulting from dendritic crystals

which grow in size until they encroach on one another. Solidified metal will be made up of a large number of crystals that have grown together. At the point of contact, they form a boundary, because they are not likely to be perfectly matched in their lattice positions. A simple analogy will show this. If two men started to build a house at different points without consulting one another, it would be the merest chance that their timbers would match when they tried to join their individual structures. So it is with metal crystals. In Fig. 7, a number of dendritic crystals are shown to have grown into contact, but with axes at random angles from one crystal to the next. These crystals are known as grains and represent a structure which is typical of many metals, including steel just after freezing.

Liquid metal which is cast into a cold container will naturally start to freeze at the surface of contact with the container. A large number of nuclei will form simultaneously, and their growth will be limited almost entirely to the inward direction—at right angles to the contact surface. They will assume a columnar form, therefore, such as in Fig. 8. The freezing of weld metal generally results in noticeably columnar grains.

Crystal Forms

It has been mentioned that metal atoms form a regu-

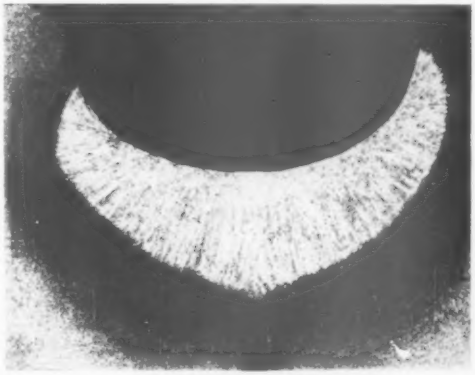
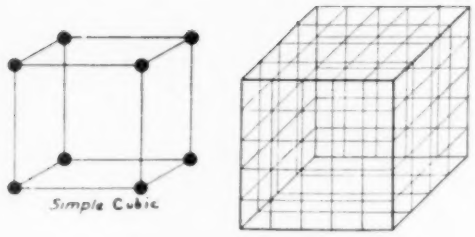


Fig. 8 Columnar crystals in weld metal

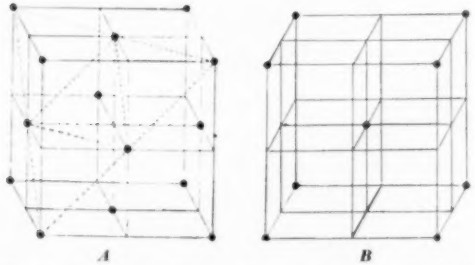


A B

Fig. 9 Simple cubic lattice and crystal formation

lar geometrical pattern in the solid state, but no details of this pattern have been discussed. Most of the useful metals assume a cubic arrangement; that is, the atoms occupy locations such that each atom is equidistant from all of its close neighbors. Reference to Fig. 9 will clarify this statement. In Fig. 9A a single cube has been indicated. If the atoms were placed at each corner of the cube only, the structure would be called a simple cubic lattice. By placing a large number of such cubes face-to-face in all directions, the configuration of Fig. 9B would result. Actually, metals assume somewhat more complicated cubic structures. In Fig. 10A, the addition of an atom to each cube face produces a face-centered cubic lattice, possessed by metals such as copper, aluminum, nickel and silver. As in Fig. 10B, addition of an atom to the center of each cube results in a body-centered cubic lattice. Chromium, tungsten and molybdenum are of this type. Iron is notable for its ability to change from one to the other form as its temperature is altered. This important property will be discussed later. Other patterns can be formed in which the basic form is hexagonal, or more complicated still. Zinc and magnesium are hexagonal.

Thus, solid metals are made up of crystals, whose internal structure can be pictured as a lattice work arranged so as to resemble an endless series of cubes or other symmetrical forms.



A B

Fig. 10 Cubic lattice forms. A. Face centered. B. Body centered

Alloy Crystals

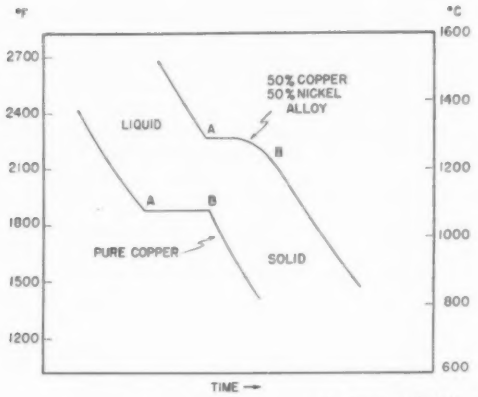
Up to this point, it has been tacitly assumed that all atoms in the crystal are alike—that is, the metal is pure. If the melt is a mixture or solution of several kinds of metal atoms, how is the situation changed? In some cases, very little change is involved. If a small amount of nickel is added to copper, the nickel atoms simply take the place of some copper atoms in the crystal lattice. Since the nickel is substituted for copper in the lattice at random points, it is considered to be dissolved in the copper crystal lattice and is termed a substitutional solid solution. In other instances, the alloyed metals may show a chemical attraction for one another and therefore tend to form a type of chemical compound whose composition corresponds roughly to a chemical formula and is relatively fixed. Solutions and compounds are almost the only two kinds of crystals that can be formed in alloys. Thus, a given alloy will be composed of one or more solid solutions and/or intermetallic compounds.

In order to set forth more clearly the way in which alloys freeze and the varieties of structures which can be formed, it will be necessary to discuss alloy equilibrium diagrams, from which considerable information about alloys can be deduced.

Alloy Diagrams

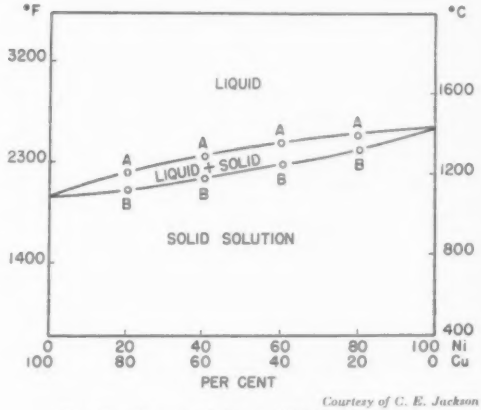
Alloy diagrams are charts which summarize the phase changes that will occur in any of a series of alloy compositions as the temperature is changed. While certain features of these diagrams are known to obey the phase rule, the diagrams can only be constructed from experimental data. According to the number of constituents making up the alloy, it is designated as a binary, ternary or quaternary alloy, having respectively, two, three or four components present. In order to understand the use of alloy diagrams, the reader may find it helpful to learn how such a diagram is obtained from laboratory experiments.

Assume that the alloys of copper and nickel are to be studied. A series of compositions of these metals is prepared and examined over a range of temperatures. For a beginning, the temperatures of melting and freezing are to be determined. One problem is to develop a technique to detect accurately the temperature at which these points occur. Since melting and freezing involve absorption or evolution of heat, one of the best methods is to allow a molten bath to cool slowly while temperature and time measurements are made. The heat of solidification will cause a jog or discontinuity in the cooling curve, and thus will be revealed. The shape of the jog will show the manner in which freezing takes place, as a pure metal always freezes at a single temperature, while alloys may freeze over a range of temperatures. The cooling curves of pure copper and of an alloy containing 50% copper with 50% nickel will appear much as in Fig. 11. At the points marked *A*



Courtesy of C. E. Jackson

Fig. 11 Typical cooling curves for copper and a copper-nickel alloy



Courtesy of C. E. Jackson

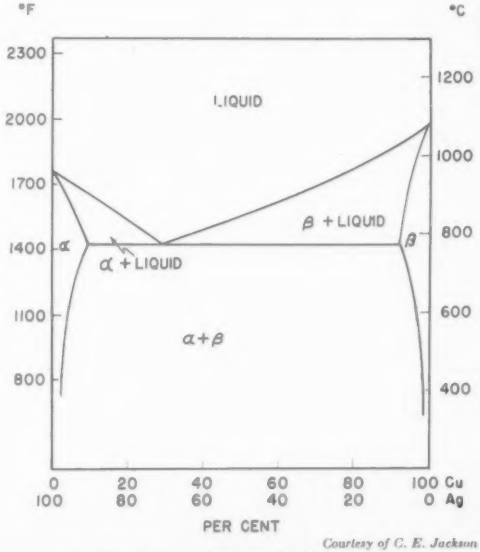
Fig. 12 Copper-nickel equilibrium diagram

and *B*, the jog begins and ends, respectively. By this evidence, the temperatures at which freezing begins and ends are ascertained.

If such information is obtained for a sufficient number of alloy compositions, the characteristics of the whole system will be determined. A single diagram can be used to plot the temperatures at which *A* and *B* occur for each alloy, as shown in Fig. 12. Temperatures are plotted on the vertical axis and alloy compositions on the horizontal axis. If all of the *A* points are connected by a line called the liquidus line, the temperature at which any alloy in the system will start to freeze can be determined by erecting a perpendicular from the horizontal axis at a point corresponding to the composition of the alloy and reading the temperature at which it intersects the line. If this particular alloy had been studied in the laboratory, its *A* point would have been found to occur at this intersection temperature; but the diagram, when sufficiently established by data, will allow the start of freezing to be predicted for all intermediate alloys without experiment. Similarly, a line connecting the *B* points, called the solidus line, will show where freezing is complete. Thus, if any alloy is heated above the *A* line, or liquidus, it will be completely liquid; if it is at a temperature between the *A* and *B* line, it will be partially molten and partially solid; at temperatures below the *B* line, or solidus, it will be completely solid. The areas or "fields" on the diagram corresponding to these conditions of temperature and alloy composition can therefore be labeled "liquid," "liquid and solid" or "solid." Since copper and nickel mixed in any proportion form only one type of crystal structure in the solid state, they are said to form a "solid solution" alloy. Any other binary alloy system in which complete solid solubility exists will possess a similar form of diagram, differing only in the location and shape of the lines denoting the beginning and ending of freezing or melting.

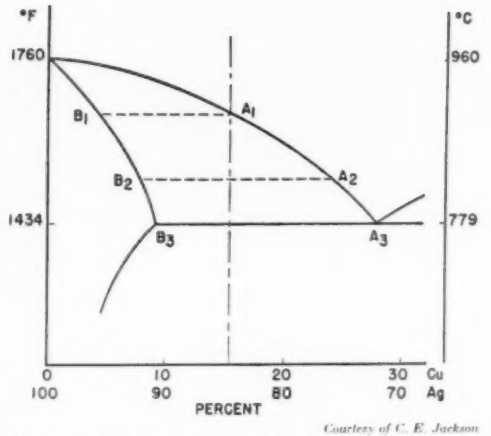
It must be emphasized that the foregoing discussion is dependent on the maintenance of equilibrium conditions, which require that any change occurring in an alloy be a reversible change. This means that any phase change due, say, to a temperature drop will be restored by raising the temperature back to the initial point. Since the validity of alloy diagrams is contingent on equilibrium conditions, they are commonly called equilibrium diagrams.

Consideration will now be turned to another type of alloy diagram in which the component metals are not capable of dissolving into a single solid solution in all proportions. In this case, the metals will produce alloys in which there are two separate phases in the solid



Courtesy of C. E. Jackson

Fig. 13 Copper-silver equilibrium diagram



Courtesy of C. E. Jackson

Fig. 14 Changes in composition during solidification

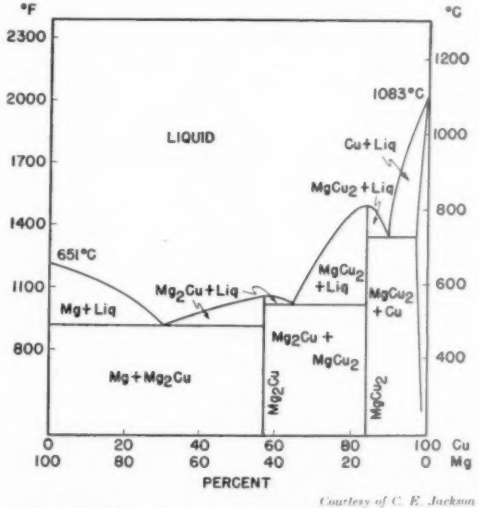
state. If cooling curves are conducted on a series of alloys between copper (Cu) and silver (Ag), the A and B points will assume the configuration shown in Fig. 13. One alloy in the series will be found to have a freezing point occurring at a single temperature which will be the lowest of any composition. However, many alloys on either side of this composition will complete freezing at this same temperature. The lowest melting alloy is called a "eutectic," and the diagram is called a eutectic diagram.

Some of the features of the eutectic diagram may be pointed out. If the portion of the diagram containing up to 9% Cu is examined, it will be noticed that freezing occurs in a manner exactly analogous to that in a solid solution system. All solid alloys in this portion will be single-phase alloys containing crystals of the solid solution labeled α. Likewise, all solid alloys between 92 and 100% Cu will be solid solution alloys containing only β phase. Thus, only the alloys lying between 9 and 92% Cu will form the eutectic type of structure.

The freezing of an alloy whose composition falls, say, at 15% Cu will be described. As the liquid alloy cools to its A temperature, solid crystals will start to form. These will be crystals of α solid solution and are called primary crystals. This brings up an important point. The crystals which form cannot be of the same analysis as the liquid from which they originate. They must be of such analysis that they, taken by themselves, constitute an alloy which is just completely solid at the temperature in question, since they *are* completely solid. The alloy filling this requirement uniquely is that located by the intersection of an isothermal line drawn from the A point of the alloy over to the solidus at the point marked B_1 in Fig. 14. As freezing continues, the crystals which form will adjust their composition to continue to meet the condition that has been stated. Thus, at a lower temperature the α crystals will have the analysis indicated by point B_2, and by the time cooling has proceeded to the eutectic freezing temperature, they will have the composition shown by point B_3.

Meanwhile, the liquid has been shifting in composition as well. Since the crystals forming are richer in Ag than the original alloy, the liquid must be depleted in that metal. Its composition, by reasoning similar to that above, must be that of an alloy just completely molten at the stated temperature. Thus, when the crystals have assumed the composition shown by point B_2, the liquid will have the analysis indicated by the point A_2. At the eutectic temperature the crystals will have the analysis shown by point B_3 and the liquid by point A_3, the eutectic alloy composition. At this temperature the remainder of freezing must take place, and it will occur by the simultaneous freezing of α and β solid crystals. Because they form simultaneously, these crystals will be intimately mixed in a structure made of thin, alternate plates of the two phases or perhaps a "salt and pepper" type of intermingling. The final solid alloy will therefore contain the larger primary crystals of α formed at higher temperatures, together with the eutectic mixture of α and β. An alloy of eutectic composition will possess a solid structure composed entirely of the α and β mixture, while any alloy between the eutectic and 92% Cu will form primary crystals of β and an eutectic structure of α and β.

As might be expected, there are many alloy systems in which the relations between the components are more complicated than those discussed above. However, these basic types have been described in some detail because the more complicated diagrams can almost all be subdivided into sectors which by themselves constitute either one or the other of these two types. Intermetallic compounds may form which are similar to chemical compounds in that there is a strong binding force between the atoms. In an alloy system an inter-



Courtesy of C. E. Jackson

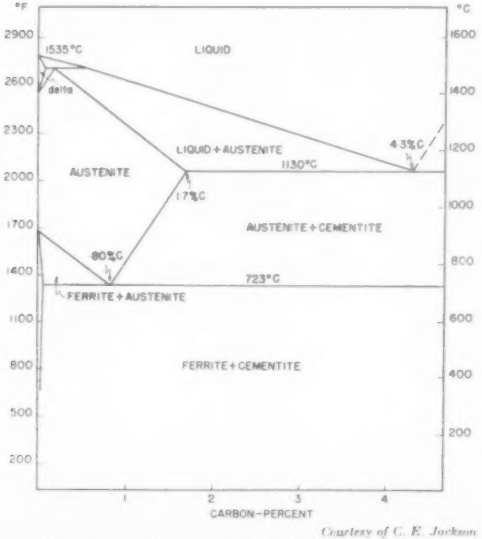
Fig. 15 Magnesium-copper equilibrium diagram

metallic compound is likely to behave much as if it were a single component. In an alloy binary system of magnesium and copper, two intermetallic compounds form; namely, Mg_2Cu and $MgCu_2$. Each of these compounds behaves as if it were a pure metal. The whole diagram shown in Fig. 15 could be reduced to three simpler diagrams by parting it at the compositions Mg_2Cu and $MgCu_2$.

As a further example of the construction of complex diagrams from simpler units, the iron-carbon diagram will be described, since it is perhaps the most important single alloy diagram in metallurgy.

The Iron-Carbon Diagram. It is important that some consideration be given to the iron-carbon equilibrium diagram, from which a better understanding of the behavior of steel can be gained, especially in connection with welding thermal cycles and with heat treatment.

The alloys of iron and carbon display more complex relations than those shown by Cu-Ni or Cu-Ag. It is possible, however, to divide the alloy diagram into simpler segments, as was stated above. In the upper left-hand area of Fig. 16 the diagram is typical of any solid-solution alloy series, except for a further complexity at low C contents which may be ignored here because it has no importance in ordinary Fe-C alloys. The range of composition included, 0–1.7% C, is usually regarded as the limit of steel compositions. Thus, all steels freeze as solid solution alloys. The solid solution formed has been named austenite. The upper right area is similar in appearance to the eutectic type of diagram. The Fe-C alloys above 1.7% C content compose the cast irons and all solidify with a eutectic present in their structure. Since few cast irons exceed 4% carbon, they usually commence freezing by the formation of primary crystals of austenite, as the diagram specifies.



Courtesy of C. E. Jackson

Fig. 16 The iron-carbon equilibrium diagram

The lower left portion of the diagram is of special significance to the unique properties of steel and departs, at least in one respect, from the basic diagrams covered previously. One might guess that another eutectic is depicted in this lower area if it were not for the fact that all of the alloys are already completely solidified before they cool to this temperature range. Therefore, it must be that a eutectic-like structure forms from a solid instead of a liquid solution. In this case, austenite decomposes to form two new phases: one is almost pure iron and is called ferrite; the other is a compound of iron and carbon, Fe_3C, which is called cementite. As will be seen later, it is this portion of the diagram which helps to explain some of the effects that are produced in steel by the thermal cycle of welding.

Solidification of Metals. Solidification of alloys, such as steel, does not occur at a fixed temperature, but within a range. Initiation of solidification begins at the liquidus and is complete at the solidus temperature (Fig. 16). The mixture of solid and liquid states extends over what is called the mushy stage. The first crystals which freeze will tend to be richer in the higher melting constituent in obedience to the principles of the alloy diagram discussed previously and illustrated by Fig. 14. As freezing proceeds, the crystals will become richer in the lower melting constituents and thus will result in a heterogeneity of composition in the final solid metal. It is this mechanism of freezing that gives rise to segregation in cast alloys. By exposure to high temperatures for a long period of time or by extensive plastic working of the metal, the composition can be equalized or homogenized considerably. Besides the reduction of segregation, working of the metal will tend to introduce refinement in grain size.

The physical properties of a solid metal or alloy are influenced by the maximum temperature of superheat of its liquid phase and the rate and mechanism of its solidification. Characteristics inherited from these temperatures are only partly removed by extensive mechanical and thermal treatment of the solid metal. The differences between weld metal and forged and cast

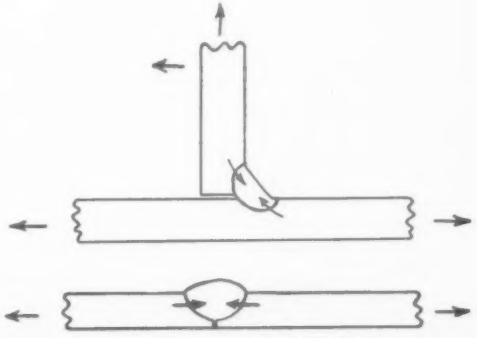


Fig. 17 Forces set up by weld shrinkage

metals are in part attributable to the high temperatures attained during fusion in welding and the rapid solidification rate which succeeds it.

Segregation

It has been pointed out that the freezing of alloys takes place over a range of temperatures and that the first crystals forming differ in composition from the melt composition. Now if conditions permit, there is a tendency for the composition to equalize itself by diffusion. But since diffusion is time-consuming, rapid freezing and cooling can readily obstruct the action, and as a result, the alloy possesses nonuniform composition from one point to the next. In welds, the freezing of the melted steel is likely to be accomplished by segregation of carbon and impurities.

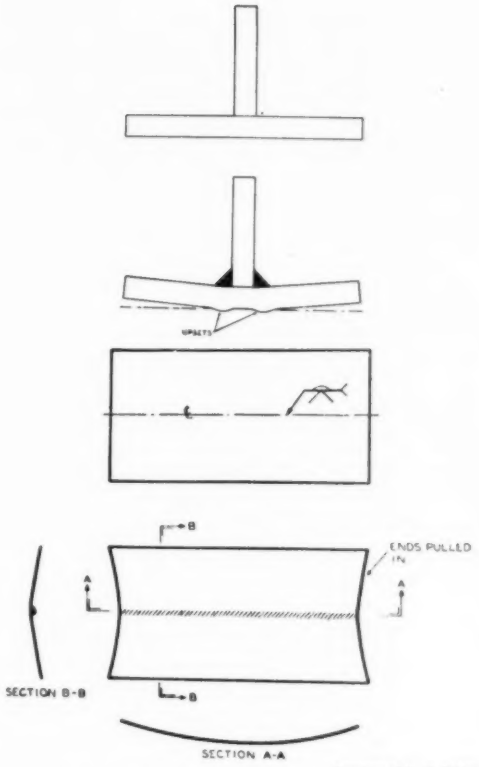
Segregation is undesirable mainly in that concentration of the impurities may be accompanied by changes in physical properties at these points with consequent lowered ductility. The columnar grains in weld metal may exhibit low ductility at right angles to their axes. Hot tears probably are encouraged by the segregation of impurities.

HOT AND COLD FORMING—WELD SHRINKAGE

During the deposition of weld metal, the plate adjacent to the fused metal is heated considerably and therefore expands in size. Later, as cooling sets in, both the solidified weld metal and the heated base metal tend to shrink in size. There are two undesirable consequences which may ensue from this action. One is the warping of the weldment, and the other is the possible formation of cracks in the vicinity of the weld. The manner in which these occur can be explained readily.

In Fig. 17, the circumstances attending the cooling of the weld zone are shown. The natural tendency of the heated area is to grow smaller in all dimensions. Almost always the adjacent material is held or supported by its own stiffness, by previous welds, or by jigging arrangements. When the weld attempts to pull in the plate edges and also grow shorter in length, it is opposed by the rest of the metal and is therefore put under tension. While the weld is still hot, it is relatively weak and plastic and thus will adjust itself by a plastic flow. As it becomes colder, it also becomes stronger, and therefore will endure a greater force before undergoing further plastic deformation. As the tensile forces build up, they begin to pull the structure more or less out of shape. If the structure is highly rigid or well supported, little warping will occur but the danger of cracking will increase.

The shrinkage forces will result in warping of the structure in a manner which is dependent on the nature of the structure and the location of the weld. In Fig. 18 some typical joints are shown with the movement of the members indicated. The stresses which give rise to warping continue to rise as the steel cools



Courtesy of L. C. Bibber

Fig. 18 Distortion in fillet and butt welds

to room temperature and, in fact, remain at relatively high levels when cooling is complete. As such, they are termed residual stresses. Such stresses are undesirable in cases where dimensional stability or corrosion resistance is important.

If the constraint of the weld environment is sufficiently severe and the ductility of the heated metal too limited to permit its adjustment by plastic flow, a crack will form either in the weld metal or the heated zone of the plate.

Weld metal is particularly susceptible to cracking at two temperature ranges during cooling. One is just below the temperature of freezing where the metal is weak and readily torn. Steel castings, in general, are prone to "hot tears" of this type if the mold interferes with shrinkage. In welds, hot cracks are promoted by concave weld surfaces, as may be present in fillet welds or weld craters.

The second temperature range in which weld cracking is observed lies between room temperature and 400° F. At this point the weld metal has become strong and the stresses are correspondingly high. It is possible that the steel is reduced in ductility by the blue-brittle effect observed around 400–600° F. The root-cracking of butt welds is commonly of this type.

Weld metal cracking can be avoided by proper sequence and proportioning of bead deposit, preheating, peening and improved joint design.

In steels of higher carbon or alloy content, the base metal becomes vulnerable to the cracking tendency. It has been found that there are three attendant circumstances which lead to base metal, or underbead, cracking. They comprise the presence of hydrogen, the existence of constraining forces, and the formation of hardened structure in the heated zone because of the rapid cooling. The hydrogen loses its solubility in the steel during cooling and therefore collects at discontinuities in the metal and builds up high pressures and localized stresses at these points. Two means can be utilized to obviate base metal cracking. If the electrode is lime-type coated, the hydrogen can be controlled at a level which does not cause cracking. The use of preheating or higher welding heat inputs may reduce the cooling rate sufficiently to avoid hardening of the steel. Underbead cracks apparently do not become a problem unless the heated zone exceeds 350 Brinell in hardness.

From what has been said here, it is evident that the weld zone, by virtue of the shrinkage accompanying cooling, is subjected to plastic flow which begins while it is white hot and continues until it is cold. In many ways the weld exhibits the same characteristics that are observed in the hot forming and cold forming of steel.

HEAT TREATMENT

It has been pointed out that the thermal cycle of the welding operation subjects the base metal to a heat treatment which may alter considerably its structure and properties. In this section an attempt will be made to explain the nature of the changes that are introduced into steel by heating and cooling cycles.

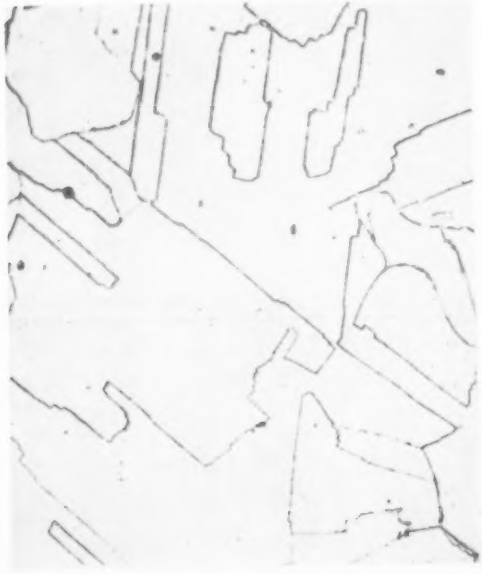


Fig. 19 Structure of austenite

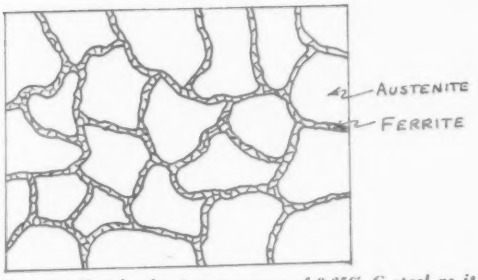


Fig. 20 Sketch of microstructure of 0.25% C steel as it would appear at 1450° F.

Metallography of Steel

The iron-carbon diagram has been shown in Fig. 16 as a summary of the physical changes which occur in steels and cast irons when the temperature is varied. It must be remembered that these are changes which are observed only under equilibrium conditions, that is, under slow heating and cooling. Since the chief concern in welding is with low and medium carbon steels, discussion will be limited to the behavior of steels containing less than 0.80% carbon.

As an example, a steel containing 0.25% C will be considered as to its phase changes when heated and cooled. A perpendicular line erected on the diagram at 0.25% carbon will intersect boundary lines of the diagram and thereby indicate the temperatures of phase changes. If the steel is heated to a high temperature below melting, it becomes a solid solution of carbon in iron crystals which have a face-centered cubic lattice. This structure is called austenite. If the microstructure could be examined at this temperature, it would appear much as in Fig. 19.

Suppose now that cooling takes place. The austenite remains unchanged until a temperature of about 1500° F. is reached. At this point, the austenite begins to break down and form a new phase at the grain boundaries. The structure, if it could be seen, would take the form shown in Fig. 20. This new phase is almost pure iron with a body-centered cubic lattice and is called ferrite. These first crystals precipitating in the austenite grain boundaries are usually called primary crystals of ferrite. This process continues until a temperature of 1350° F. is reached. Meanwhile, the austenite has been losing iron and therefore builds up in carbon content until it reaches 0.85% carbon at 1350° F.

At 1350° F., the remaining austenite must disappear completely. It transforms to a structure which is very similar to the eutectic structure described previously; but because the action takes place in the solid state, the new structure is called a eutectoid and is given the name, pearlite. Pearlite is a mixture of ferrite and a

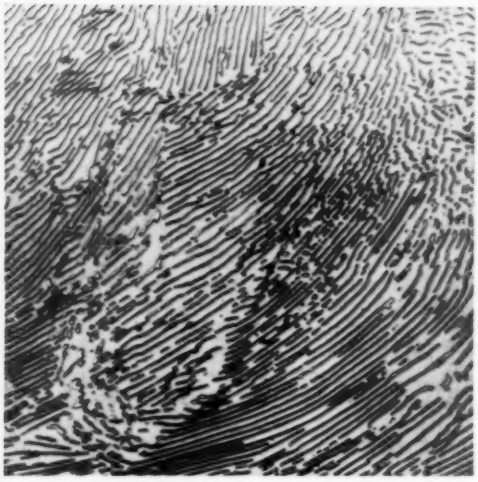


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Fig. 21 Typical lamellar microstructural appearance of pearlite. 1500 ×

compound of iron and carbon called cementite. These two phases are mixed in an intimate, laminated structure which at high magnification appears as shown by Fig. 21. On further cooling, no additional changes occur in the steel and the final microstructure found at room temperature will therefore consist of the white primary ferrite crystals and the dark pearlite aggregates illustrated in Fig. 22.

The range of temperatures in which these structural changes occur is called the critical range. They can be repeated in the steel by heating and cooling as often as we please. In heating, the process will be exactly reversed, the pearlite first changing to 0.85% C austenite and then the primary ferrite gradually redissolving in the austenite.

Since consideration has been given only to a steel containing 0.25% carbon, the question arises as to how other carbon contents will modify the behavior on heating and cooling. Their principal effect is to alter the relative amounts of primary ferrite and pearlite which form. Since virtually all the carbon is tied up in the cementite of the pearlite, it may be expected that the volume of pearlite will vary directly as the amount of carbon in the steel. Thus, at 0% carbon only ferrite will form. At 0.85% carbon, only pearlite will form. This relation can best be shown by a series of micrographs in Fig. 23, in which the room temperature structure is shown as a function of carbon content.

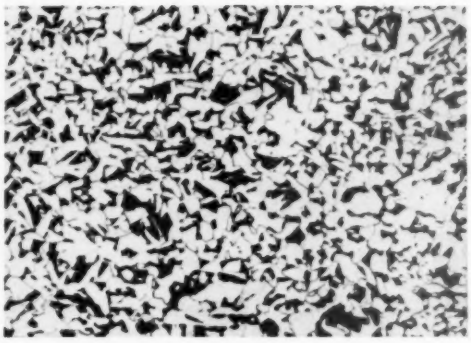

Fig. 22 Structure of 0.25% C steel when cooled slowly from 1600° F.

Effect of Cooling Rate

In the previous section, the phase changes were described for slow heating and cooling rates for which equilibrium conditions were assumed. What happens if cooling is accelerated? It is here that some of the most important and interesting effects are produced in steel.

It may easily be surmised that fast cooling rates will tend to interfere with the normal phase changes in steel and even produce structures which should not ordinarily form. The effect of gradually increased cooling rate on the structure changes will be traced for the same 0.25% C steel considered previously.

With moderately accelerated cooling, the primary ferrite may not have full opportunity to form, and the pearlite will likely become more finely laminated and, because fewer primary ferrite crystals formed, will be

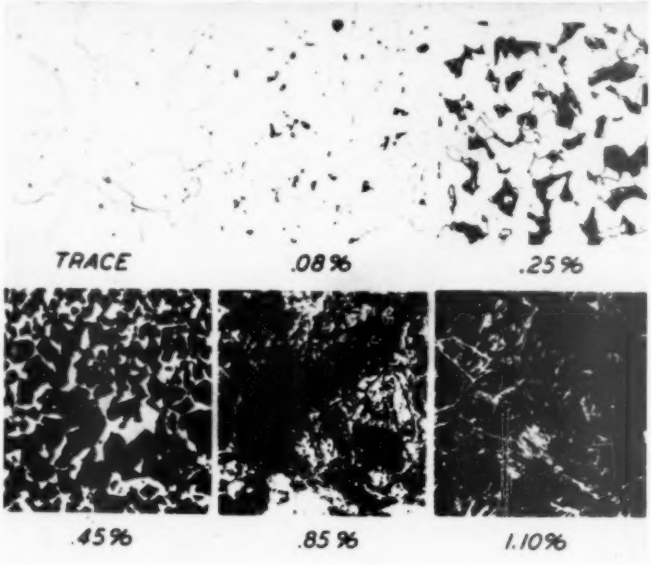

Fig. 23 Structure as a function of carbon content. All steels slowly cooled

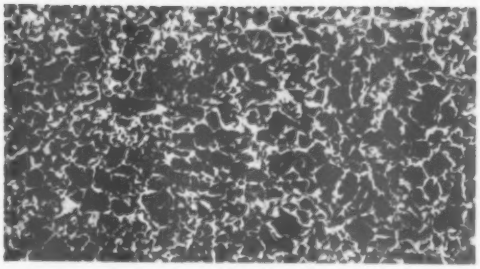

Fig. 24 Structure of 0.25% C steel when cooled fairly rapidly from 1600° F.

somewhat more voluminous. Figure 24 illustrates this action when compared to Fig. 22.

With still higher rates, the ferrite will be suppressed further, and the pearlite will become so finely laminated that it cannot be resolved by the microscope. Finally, the cooling may reach a velocity at which the austenite cannot transform completely to ferrite and pearlite. A new structure now makes its appearance. The austenite which fails to transform normally is retained to much lower temperatures but eventually changes over to body-centered cubic crystals in which the carbon is held in a super-saturated state. This structure is called martensite and appears as the gray-white areas of Fig. 25. If the cooling rate is sufficiently rapid, the austenite may be forced to form a completely martensitic structure. Martensite is relatively hard and strong compared to the pearlite-ferrite structure, and is sought in steel parts which are to resist wear or high stresses. But it is also limited in ductility and therefore is generally avoided in the structural steels.

One of the most significant effects of adding alloying elements to steel is their power to enhance the sluggishness of the austenite to transform upon cooling. Thus, with alloys present, the rate of cooling which avoids the usual products and produces martensite need not be so high. Alloys are said to increase the hardenability of steel. Now the alloying elements vary considerably in their power to increase hardenability. Molybdenum and manganese are very potent in effect; chromium and tungsten are fairly strong; nickel, silicon and copper are relatively weak. It follows that larger amounts of the latter alloys must be added to equal the effect of elements such as Mo and Mn. As alloying elements are added to steel, the cooling rate necessary to produce martensite will be shifted from the drastic water quenching needed for plain carbon steels to air cooling or even furnace cooling with high alloy content.

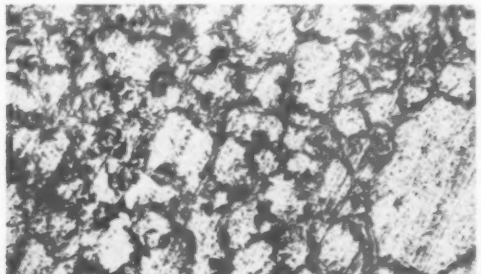

Fig. 25 Structure of 0.25% C steel oil-quenched from 1600° F.

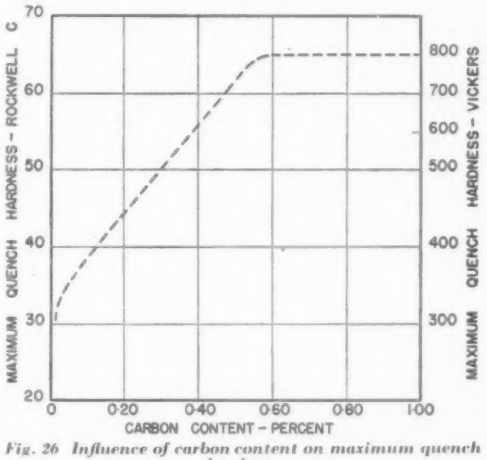

Fig. 26 Influence of carbon content on maximum quench hardness

Types of Heat Treatment

The ability of steel to change its structure when given a thermal cycle, together with the alterations in properties which accompany these changes in structures, is responsible for the great usefulness of steel in so many different applications. No other metal can be manipulated to give the wide ranges of hardness, strength and ductility that can be obtained in steel. These ranges of properties are obtained by a number of heat-treating methods.

Annealing consists of heating the steel above the critical range followed by slow cooling. It is used to obtain maximum softness and ductility, refine the grain size, relieve stresses and the effects of cold working. Steel which is to be cold formed is frequently annealed first.

Normalizing is carried out by heating the steel above the critical range and cooling it in air. It is used to refine grain size, control primary ferrite precipitation, minimize segregation and improve mechanical properties.

Hardening is performed by heating above the critical range (for steels below 0.80% C, at least) followed by quenching in water, oil or air (or some other medium) so as to form martensite. It is used to obtain high hardness, strength and wear resistance.

Tempering consists of heating hardened steel to some temperature below the critical range. Freshly hardened steel is generally too low in ductility for use and can be softened and toughened by reheating the martensite. The higher the tempering temperature, the greater the softening and toughening. The martensite, being a nonequilibrium structure, gradually breaks down to a ferrite matrix with particles of iron carbide of increasing size. Incidentally, the initial hardness of the martensite is dependent on the carbon content of the steel, as indicated in Fig. 26. Thus, for high hardness, the steel must contain high carbon. Here the tempering temperature will be kept low. For lower hardness and greater toughness, carbon will be kept down and the tempering temperature may be fairly high.

Before leaving the subject of heat treatment, some mention should be made of the meaning of grain size. Whenever steel passes through the critical range, a new crystalline structure forms, and the new crystals are small in size. It is because of this that grain refinement of steel can be accomplished by a simple heating operation. If the heating is continued to a temperature high above the critical, the small austenite grains are able to coalesce and grow large. Now this might not seem of any importance to the ferrite-pearlite structure which will reform upon cooling, since the austenite will be entirely obliterated in any case. However, the austenite grain size controls the distribution of the primary ferrite forming in the boundaries as well as the pearlite, and the mechanical properties will be affected, as well, particularly toughness. The effect on the structure can best be demonstrated by comparison of fine-grained and coarse-grained microstructures, as depicted in Fig. 27. It should be noted, then, that a reference to the grain size of the steel concerns the grain size of the austenite just before it transformed to lower temperature structures.

Heat Treatment by Welding

It must be apparent that the production of a fusion weld in steel is always accompanied by a heating of the solid metal adjacent to the weld in which maximum temperatures will vary continuously from just below melting next to the fusion line to barely detectable warming several inches away from the weld. The base metal, therefore, receives a complex and graded heat treatment in this heat-affected area. Figure 1, shown previously, represented the zone surrounding the weld that has been heat treated.

The exact effects of the weld heat on the steel will depend on how high the temperature goes, how long it is heated and how rapidly cooling proceeds thereafter. Some discussion of the constitution of the heated zone will be necessary to understand the actions taking place.

The maximum temperature and time of heating will determine whether austenite forms, how well the carbon and alloys dissolve in the austenite and how coarse the grain size becomes. The cooling rate will be of concern principally in those areas where austenite forms and must revert to lower temperature products. The effect of cooling rate on this transformation has already been outlined.

In Figure 28, a polished and etched cross section of a weld is shown at 50 diameters. The weld metal, *A*, appears on the extreme right of the photograph. Just to the left of the fusion line can be seen large, black grains, *B*, outlined by white boundaries. This struc-

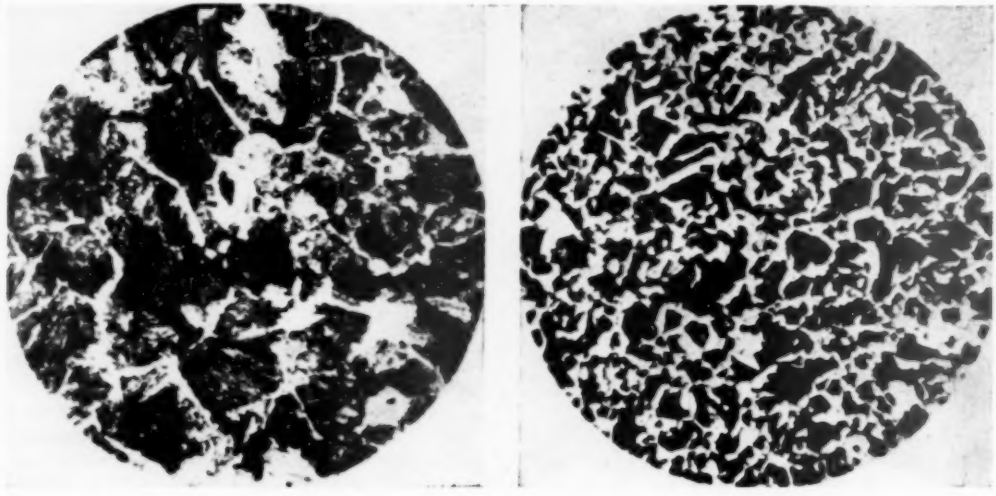

Fig. 27 Comparison of structures formed from coarse and fine grain austenite

ture is pearlite surrounded by primary ferrite. As one looks further to the left, away from the weld, he can see that the grains become progressively much smaller, *C*. The temperature gradient has produced a grain size gradient. Still farther left, at *D*, the structure appears mixed and indistinct. Here the heating has not been entirely through the critical range, and only partial transformation has been able to take place. At the extreme left, *E*, the original plate structure appears undisturbed. Heating has not reached the critical range at all. The most noticeable changes to the steel apparently take place close to the fusion line of the weld.

Next, the influence of cooling rate may be examined by comparing Fig. 28 with Fig. 29, in which the same steel is shown with weld zones resulting from high heat input and low input during welding, respectively. In Fig. 29, the coarse grains next to the fusion line now contain considerable amounts of gray-white structure which can be identified as martensite. In other words, this area has been hardened just as though it were quenched, say, in water. Thus, the welding conditions can result in fast or slow cooling, depending on the amount of heat supplied and the rapidity of its dissipation.

Now, what are the factors which determine the nature of the heated zone and its cooling period? They may be listed as including arc current, travel speed of the electrode, thickness of the plate and plate temperature. High currents and low travel speeds provide a large amount of heat per inch of weld ,and thus encourage slow cooling. Thick plates and low plate temperatures permit rapid dissipation of the heat and hence rapid cooling. To control the cooling rate and, with it, the heat treatment of the weld, then, the chief means at the welder's disposal are the welding current and travel speed (that is, the size of the weld bead), and the plate temperature (preheating). The higher the carbon and alloy content of the steel, the more readily it will harden in the heated zone and, therefore, the slower will have to be the cooling rate which avoids hardening.

If hard structure does form in the heated zone, it can be softened by postheating or tempering. This may take the form of actual heating by flame or furnace of the weldment or it can be done with subsequent weld beads which reheat the old heated zone, refine the grain and soften the structure. To get this effect, proper proportioning and location of the beads are necessary. An example of heat treatment by multiple beads is presented in the weld cross section of Fig. 30.

PHYSICAL PROPERTIES VS. MICROSTRUCTURE

In the preceding section, the effect of heat treatment

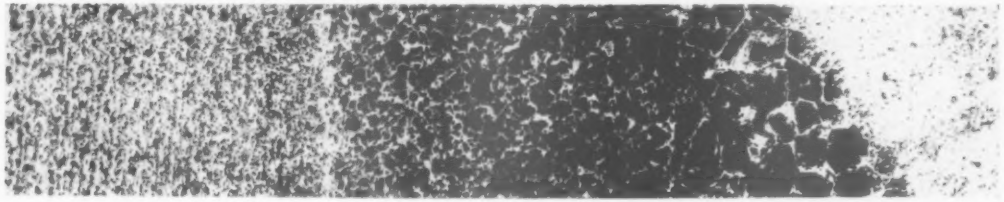

Fig. 28 Microstructures present in the weld zone: 3/4-in. 0.25% C plate, 175 amp., 6 in./min.

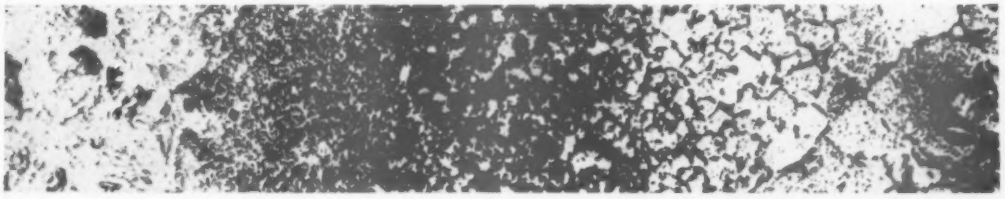

Fig. 29 Microstructures present in a weld zone using low heat input: 3/4-in. 0.25% C plate, 175 amp., 6 in./min.

Fig. 30 Cross section of a multipass weld

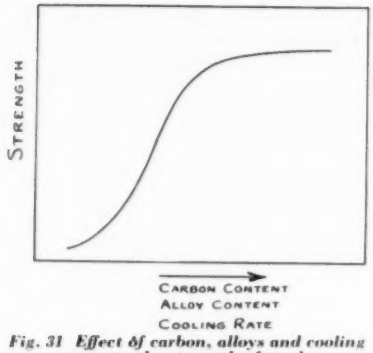

Fig. 31 Effect of carbon, alloys and cooling rate on the strength of steel

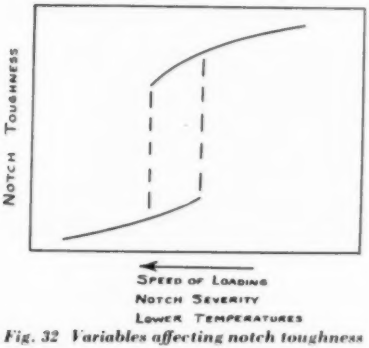

Fig. 32 Variables affecting notch toughness

on the microstructure of steel has been described; and, in addition, the microstructures which can be produced in the weld area by the thermal cycle of welding have been discussed briefly. It remains to point out how these structures in the vicinity of the weld can affect the mechanical properties of the steel and, therefore, its service performance.

Properties Important in Structures

In order to build a steel structure which will fulfill its requirements satisfactorily in the intended service, it is generally necessary to see that the steel possesses certain mechanical properties which determine its usefulness in the structure. These properties are strength, ductility and notch toughness.

The strength of the steel, specifically its yield strength, determines the load-carrying capacity of the structure. If it were not for other factors, the highest strength possible would always be desired in the steel.

The ductility of the steel is a measure of its capacity to be cold formed during manufacture and later its ability to absorb occasional overloads in service without rupturing.

The notch toughness of steel is related to its resistance to low-temperature operation, shock loading and the effects of localized stress raisers in the structure caused by inclusions, notches, weld undercutting and other accidental discontinuities present.

The strength of a steel is dependent largely on three factors: the carbon content, the alloy content and the rate at which it was last cooled from above the critical range. The manner in which strength varies with these is shown diagrammatically in Fig. 31. It will be noticed that the strength can be raised by increasing any or all of the three factors. They all act to reduce the amount of primary ferrite formed, which is a weak constituent of steel, and, except perhaps for carbon, act to increase the fineness of the pearlite, and thus to strengthen it.

In steel, ductility tends to vary roughly in an inverse manner to the strength. Since strength can be obtained only by sacrificing ductility, there is a limit to which the strength may be raised with safety. In structural steel, alloys may be added to raise the strength without the loss of ductility that increasing carbon or faster cooling rates would entail. The low-alloy, high-yield strength steels have been developed to take advantage of this fact.

The notch toughness of steel requires additional consideration, if a clear understanding of its significance is to be provided here. All metals can be broken more easily if the section is notched before loading. This fact is explained by the statement that the presence of the sharp notch has concentrated or raised the stresses in the vicinity of the notch and therefore a breaking load is built up more readily. Ordinary steel differs from copper or aluminum or nickel in that it becomes highly sensitive to notch effects if the temperature is lowered below a critical level, if the rate of loading is raised, or if the sharpness of the notch is increased, or if all three are changed together. This behavior is shown in the diagram of Fig. 32. Note that there is a range of temperature, loading rate or notch severity where the steel drops in toughness to a small percentage of that exhibited under less severe conditions. If the service conditions of a given steel structure are correspondingly severe, there is danger

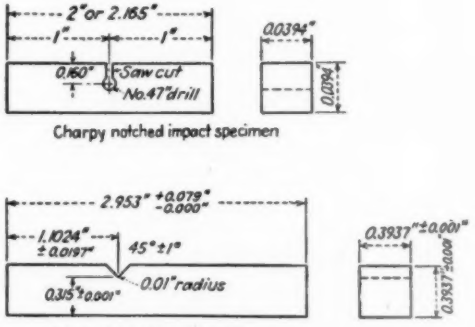

Fig. 33 Dimensions of Charpy impact specimen

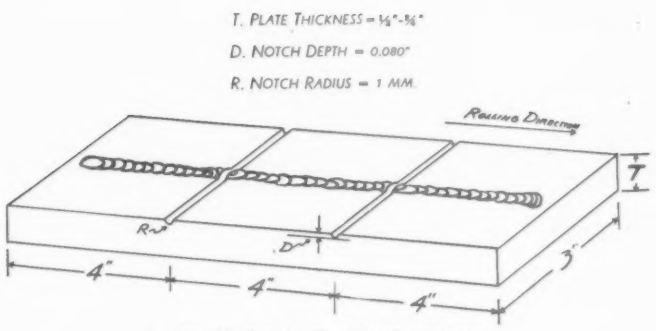

Fig. 34 Longitudinal bend specimen

that the steel will fail because of its loss of toughness. During the past several years, failures of ships, bridges and pressure vessels have been traced to this cause and have led to extensive investigations into the notch sensitivity of steel.

It is evident that means of testing the notch toughness of steel should be available. This may sound easier than it is. There are many specimens which have been developed to test the notch behavior of steel, but there is always difficulty in applying the information supplied by them to the expected behavior of actual structures. Two specimens will be described here.

The V-notch Charpy test is made on the specimen shown in Fig. 35. Testing is carried out by placing the specimen in a jig so that it is supported at its two ends. A pendulum is allowed to fall and strike the specimen at the center, but on the face opposite the notch. The energy in foot pounds lost by the pendulum in rupturing the sample is used as a measure of the toughness of the steel. Specimens are tested over a range of temperatures so that the transition from tough to brittle behavior may be observed. The quality of the steel can then be expressed in terms of the temperature to which it can be cooled before becoming excessively brittle. Note that this is a relative temperature only, useful for comparing heats of steel or effects of heat treatment, cold work and the like.

The second specimen, the longitudinal notch-bend test shown in Fig. 34, has been found useful for studying the effects of welding on steel. The welding is most conveniently carried out in the form of a longitudinal bead-on-plate deposit. It is tested under slow loading instead of impact, and toughness may be measured by the angle of bend up to the maximum load, energy absorbed during rupture or by still other observations. Again, a range of temperatures of testing must be employed to obtain the transition in notch toughness. Results obtained from both types of specimens will be presented in the succeeding section.

Effects of Welding on Mechanical Properties

If strength were the only property of importance in steel, the effects of welding would be of very little concern. The cooling rates present in the heated zone tend to increase strength if anything, and thus a fully welded joint will be as strong or stronger than the unwelded plate so far as yield strength as obtained in a tensile test is concerned. It is almost always lack of ductility rather than lack of strength which is responsible for any loss of load-carrying capacity in a properly welded structure.

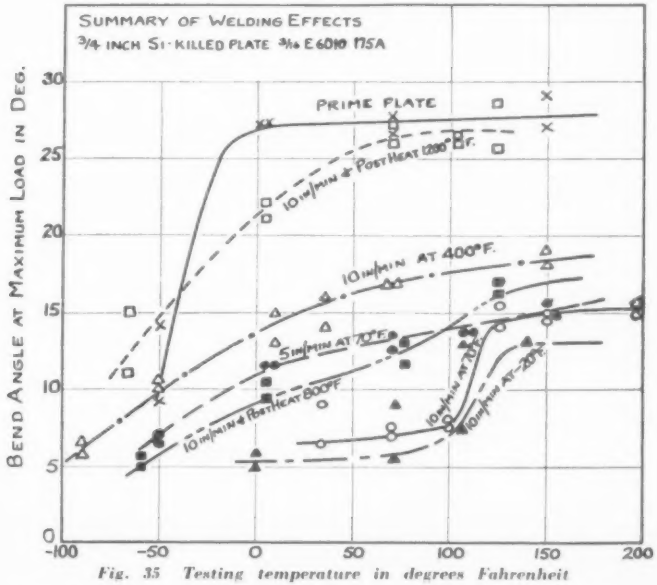

Fig. 35 Testing temperature in degrees Fahrenheit

Ductility will generally be lowered by the introduction of welding. The heated zone of the weld contains coarsened grain structure with raised hardness and will start cracking after relatively little plastic deformation. This loss of ductility may not impair service properties seriously but will limit its cold-forming capacity.

It is the property of notch toughness that may be drastically reduced by welding. Without any consideration of the changes in microstructure due to welding, the fact that the structure becomes a monolithic—a one piece—section intensifies the problem of maintaining toughness. Unlike bolting

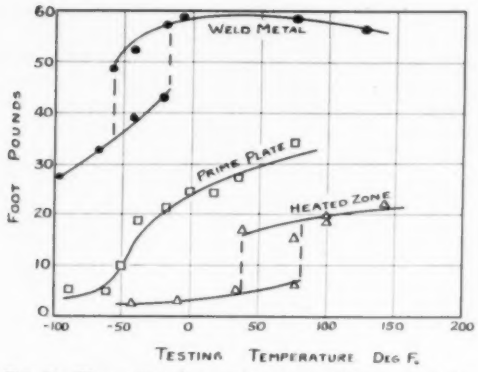

Fig. 36 Charpy toughness of various weld zones: 3/4-in. 0.25% C plate; standard A.W.S. filler metal test sample

Fig. 37 Initial crack in coarse grains of the weld-heated zone

or riveting, welding introduces a constraint which may extend throughout the structure. If failure originates at some stress-raising discontinuity, the crack can readily propagate across the whole section instead of stopping at the edge of the original plate.

The longitudinal notch-bend test illustrates nicely the reduction in notch toughness by the metallurgical effects of welding. In Fig. 35, tests are reported on unwelded 0.25% carbon, 3/4-in. plate and also on welded plate in which several welding conditions were introduced. The transition temperature is found to be raised very considerably by welding. Also, the maximum ductility displayed by the welded pieces is only about half that of the prime plate. Slower welding speed or preheating improved the performance greatly, as is shown.

In order to discover why the welded plates were so much poorer than the unwelded plates, Charpy tests were machined from welded plates so that the notched section was located in weld metal in one set, in the heated zone in a second, and in unaffected base plate in a third. In Fig. 36 it will be observed that both the weld metal and the prime plate are far superior to the tests made on the heated zone, and it is the latter which must be responsible for the reduced properties.

Now the heated zone is itself a complex aggregation of coarse and fine grains, partially and completely transformed structure, and so it is desirable to know more exactly why this area is notch sensitive. By taking welded notch-bend tests and bending them just a few degrees and then interrupting the test so that cross sections can be made of the notch area, it was possible to detect where the first cracking originated. In Fig. 37, a micrograph is shown in which a crack has originated in the grain boundaries of the coarse grains just below the fusion line. Apparently, this structure is a source of cracks because of its low ductility.

It is not possible to take a weld and determine the toughness of each type of structure present in the heated zone because they are so intimately associated in thin layers next to one another. An approximation can be obtained, however, by preparing Charpy bars of the same steel and subjecting the bars to a series of heat treatments which simulate the heat treatment of welding and therefore furnish in each bar a uniform structure typical of a certain segment of the weld-heated zone. It was found that Charpy bars heated to 2100° F. and quenched in mineral oil would match the coarse grains of a weld produced at 10 in./min. and 175 amp. on 3/4-in. plate. Likewise, 1600° F. would provide fine grain structure matching that farther away from the fusion line, and 1400° F. would match the material

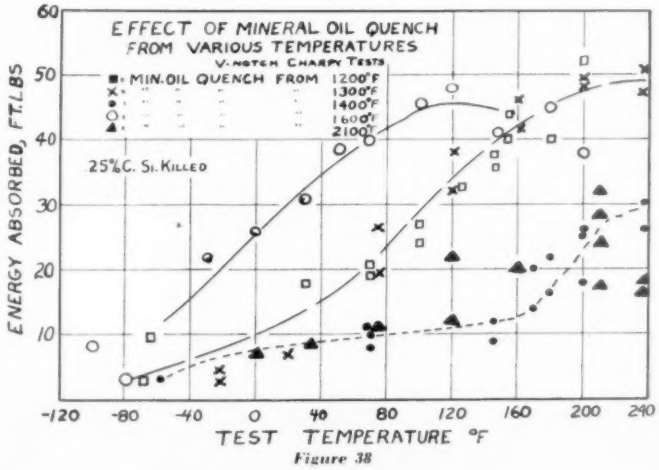

Figure 38

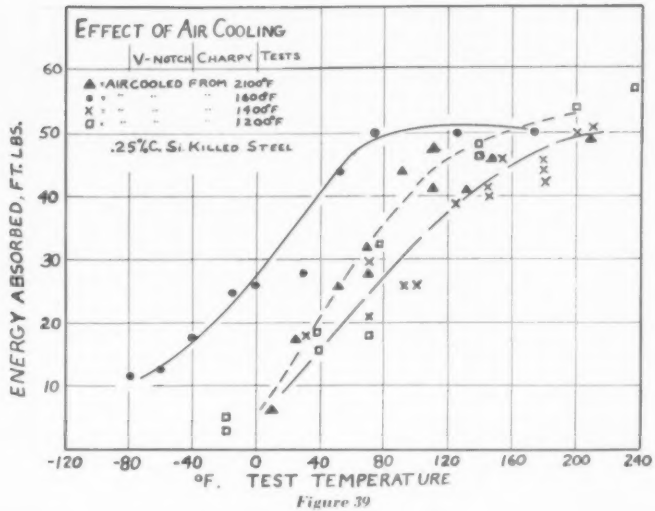
EFFECT OF AIR COOLING
V-NOTCH CHARPY TESTS
▲ AIR COOLED FROM 2100°F
● " " " 1600°F
X " " " 1400°F
□ " " " 1200°F
.25% C. Si. KILLED STEEL
ENERGY ABSORBED, FT. LBS.
°F. TEST TEMPERATURE

Figure 39

heated to within the critical range of the steel. And so on for any zone of the weld which was to be reproduced.

The results of the heat treatment of Charpy bars are given in Fig. 38. Note that the coarse-grain specimens treated at 2100° F. are particularly poor, while the 1600° F. fine-grained samples are actually better than the prime plate. Note, also, that specimens heated within the critical range, 1400° F., are as poor as the coarse-grained series. It appears that several areas may be to blame for the impaired properties of welded plate. It must not be overlooked, either, that the manner in which these structures are assembled in the weld zone may bear on their behavior. It has been suggested that the wide heated zone produced at lower currents and travel speeds may be much more harmful than the narrow zone resulting when high currents and high travel speeds are utilized.

A second group of tests was heat treated with cooling carried out in air instead of oil. Note that in Fig. 39 the coarse-grained tests and those heated to 1400° F. are not nearly so inferior to the prime plate as they were at the fast cooling rate. Thus is explained the improvement in notch properties that results from raising the weld heat input.

In summary, the reduction of notch toughness caused by the application of welding to steel can be ascribed to the monolithic nature of the welded construction, the coarsened and embrittled microstructures of the weld heated zone and the notches arising from root conditions or undercutting during welding.

Minimizing Effects of Welding

The deleterious effects of welding can be minimized by a number of steps: (1) proper choice of steel composition, (2) heat treatment of the steel before welding, (3) proper welding technique and (4) postheating of the weldment.

The composition of the steel is undoubtedly the most important single variable which determines the level of its notch toughness. Low-carbon content with alloys to supply the needed strength can be of great assistance. Figure 40 shows the dominating role played by carbon

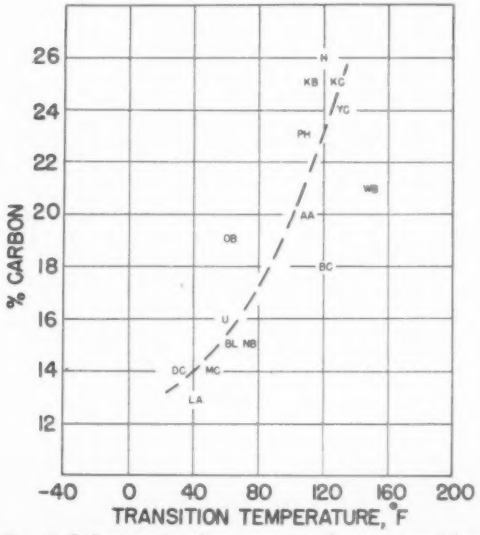

Fig. 40 Influence of carbon content on fracture transition temperature

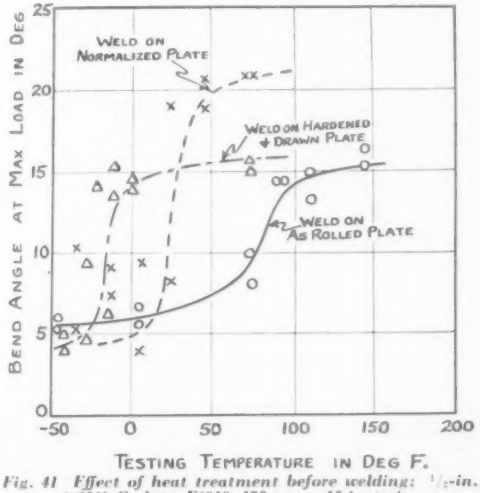
BEND ANGLE AT MAX LOAD IN DEG
WELD ON NORMALIZED PLATE
WELD ON HARDENED & DRAWN PLATE
WELD ON AS ROLLED PLATE
TESTING TEMPERATURE IN DEG F.

Fig. 41 Effect of heat treatment before welding: ½-in. 0.25% C plate, E6010, 175 amp., 15 in./min.

in setting the level of transition temperature. The steels represented are a mixture of carbon and alloy, killed and semikilled heats. Low nitrogen content and full deoxidation are also known to be favorable to notch toughness.

Heat treatment before welding can be beneficial. In Fig. 41, hardening and drawing or normalizing are shown to produce lower transition temperatures in welded specimens than that obtained from welds deposited on as-rolled plate. Of these pretreatments, only normalizing would be practicable on structural steels.

Controlling the welding conditions is important in preserving notch toughness. Figure 35 has shown how a higher heat input or preheating can be effective in minimizing loss of toughness. In multipass welds, proper proportioning of the subsequent passes can be used to heat treat the heated zones of the underlying passes. Whenever possible, the last pass should be located in weld metal, since it resists the effect of the thermal cycle better than most base plate materials.

Postheating to 1150° F. can be strongly beneficial to welded plate. While this is commonly called stress relieving, the metallurgical tempering effects are probably more important to notch toughness than removal of residual stresses. Even reheating the weld with a torch may be of some benefit, as is shown in Fig. 42, which also contains test results demonstrating the usefulness of furnace postheating.

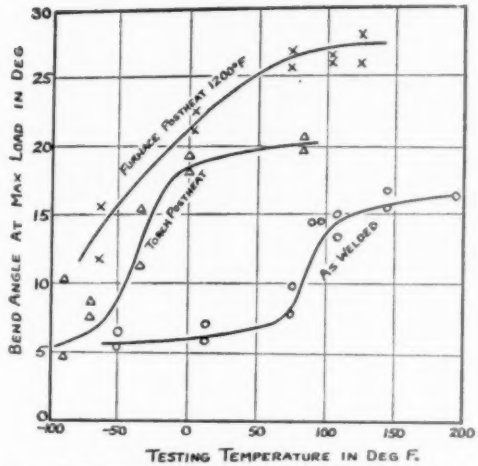

Fig. 42 Effect of postheating on welded plate: 1/2-in. 0.25% C plate, 3/16 E6010, 175 amp., 15 in./min.

CONCLUSION

An attempt has been made here to point out some of the metallurgical phenomena which are present in the arc welding of steel. A discussion of such limited scope is bound to be replete with oversimplifications and half-truths. If these paragraphs will serve only to acquaint the reader with the fact that welding carries with it certain metallurgical problems and if he will be stimulated to look to the literature for more complete information, they will have performed their intended service.

Arc Phenomena with Electrodes Moving at High Speed

Authors' Closure

The discussions by Messrs. Orton and Needham will be taken up in the order of the points raised.

The section through the anode spot shown in Fig. 4 does not necessarily represent the contour of the molten pool. High-speed movies seem to show that the metal is drawn up into a mound before the arc transfers to a new anode spot which would indicate that the force action causing the metal peaks occurs during the arc process rather than after current cutoff. It is hoped that further studies now under way will clarify this matter.

The 1/4-in. diameter bare steel rod was polished with fine emery cloth and cleaned with carbon tetrachloride.

The voltage values pertaining to Figs. 10 and 11 are average values as read on a recording millivoltmeter and shunt arrangement. It is difficult to make an accurate comparison between such voltage measurements and those made on the oscillograph. The wording in the text denoting "arc length" when referring to Fig. 11 is incorrect. This should be "electrode separation" as noted on the figure. Messrs. Orton and Needham are quite correct in stating that a determination of the true arc length is difficult to make when the arc is extended to its maximum length. However, when a new spot is formed directly beneath the electrode, the arc length then corresponds closely to the electrode separation. This permits a more accurate plot of the voltage-arc length curve when correlated with oscillographic records. This has been done and is covered in a paper now under preparation. The arc voltage of 28.5 shown in Fig. 10 is an average value for the current range plotted and cannot

(*Continued on page 357*)

Paper by W. B. Kouwenhoven and T. B. Jones was published in the September 1948, *Welding Research Supplement*, pp. 470-s to 475-s. Discussion by L. H. Orton and J. C. Needham was published in the January 1949, *Welding Research Supplement*, p. 14-s.

Welded Units for a Vehicular Tunnel

The know-how of a shipyard to construct large all-welded ships is utilized for the fabrication of tunnel sections

by Clyde M. Leavitt

A SHIPYARD established ten years ago specifically for the construction of all-welded ships recently became engaged in various other welded steel projects such as ship conversion and repair, tanks, pressure vessels, dredging pipe and structural steel work. To these activities the engineering and working crafts which had built more than one hundred fighting ships, cargo vessels and luxury liners, applied their know-how. This transformation took place at the shipyard of The Ingalls Shipbuilding Corp., at Pascagoula, Miss., where presently one of the out-of-the-ordinary assignments is that of constructing the immense units for the structure of a vehicular tunnel underneath the Houston Ship Channel and to be known as the Pasadena Tunnel.

The tunnel structure consists of four tube sections and two transition sections. Each section is 375 ft. in length and is 35 ft. in width. The transition sections are 12 ft. long and 35 ft. in width. Over 3000 tons of steel patterned to precision and design makes these tubes the most sturdy type of construction used today.

Incorporated are the building skills and expediency of construction such as have been mastered at Ingalls in their highest degree—those of welded steel. The tunnel tubes are stitched together by electric welding with every niche and connecting part meshed into one piece by molten metal, as was the *Exchequer*, the first 17,000 ton ship molded here and the world's first all-welded cargo-passenger vessel also.

Similarity with Ship Construction

With the exception of machinery and other outfitting, a part of every ship, the requirements to bring the tunnel tube sections to completion are comparatively the same. Work in the Mold Loft, in man hours and material was equal to that necessary when preparing templets and patterns for the hull of one of the large vessels. These were taken from plans and drawings engineered by Palmer & Baker, Inc., Consulting Engineers, Mobile, Ala., and the Ingalls Engineering Division, all of which bore the approval of Merritt-Chapman and Scott Corp., world's largest general contractor, New York.

The Fabrication Shop and the Platens also entered into the activity. In the Fabrication Shop the diaphragms were cut, welded and formed into huge half-circle supporting elements. The diaphragms were transported to the Platens for installation. On the Platen a large jig was erected over which the inner shell plates were formed into half circles (Figs. 1-3). The diaphragms were then set in position over the inner plates and welded in place; forming a half-circular-shaped subassembly of the thirty which were

Fig. 1 Platen view—fabricating subassemblies

Fig. 2 Placing subassembly on tunnel tube section

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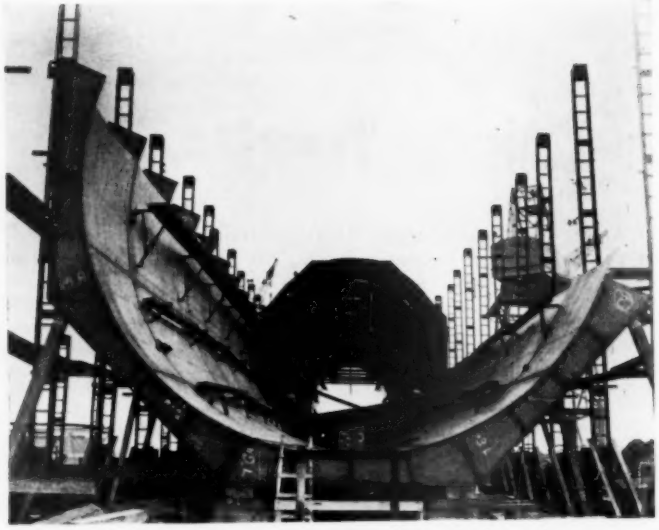

Fig. 3 View of partially constructed tunnel tube section

fabricated on the ground and all of which when put together became one complete section of the tunnel tube.

On the ways the bottom subassemblies were placed. Later, the top subassemblies were placed by crane, half for half, upon the bottom construction. All units were then welded into place making a continuous tubular structure. The subassemblies which write finish to the tube, and are last to go into place, will be two large bulkheads, one at each end. The outer shell plates are installed before the bulkheads are put into position.

In the construction of the tunnel tubes a standard sequence is being used with allowance for shrinkage, which upon completion of all-welding the sections will conform to design calling for an over-all length of 375 ft. The major portion of welding on the structures consists of a straight, single-pass method. There is some intermittent welding in various locations. All-welding is of the same classification as that used in the construction of ship hulls.

Throughout the interior of the massive steel tubes a series of small steel bars runs around the entire circumference, longitudinally from one end to the other (Fig. 4). These are to be used for reinforcement of the inner lining of concrete work to be installed at the tunnel location.

The formation of this web of steel bar arrangement was achieved with the automatic stud-welding method and is believed used for the first time in construction of this type (Fig. 5). Considered a new departure, stud welding of all supports not only speeded production but provided a cleaner, more neat job than when each stud is tacked, then made secure by hand welding around the base.

With the section completed and ready for launching, many preparations had to be made (Fig. 6). Where the average vessel furnishes its own protection and support through construction against the strains of a launching, such provisions had to be made available in temporary manner only for the duration of the launching. The lauching of these sections held much the same operations as those necessary to send the average ship into the water. Missing, of course, is the familiar nautical fanfare, the sponsor and the ship. The latter is replaced by the immense steel tunnel tube section. Regular shipways were used to float the section.

The sections will ride the ways on five 35-ft. sleds instead of on continuous ways as do ships of equal length. The lighter weight of the tunnel tube structure makes this difference possible. The burn-off plate used for releasing vessels will be replaced by two trigger shores. These will be located at the second sled from the stern end.

Special shoring is installed inside the center of the section which consists of a large number of sturdy shores arranged in perpendicular positions amidship. To protect the center of the tube during the period when the stern hits the water and the forward end remains on the ways, heavy angle stiffeners are welded atop the structure amidship. These add strength for a center length of 140 ft. In addition, three "A" frames are erected at the location of the fore poppet or crush sled, forward, to give required support when the sections pivot.

Underneath the section are 24 sand blocks for support which will be removed along with grease irons before the launching. Otherwise the steel hulk will rest on the five sleds.

The section, with watertight bulkheads, assumes the floating buoyancy of a large pontoon (Fig. 8). Handling the launching procedure operations is a crew of 15 men.

After launching, the section is taken by tugs to the outfitting basin where it will be warped fast to one of the piers. Here, shoring, etc., will be removed from the inside through watertight manholes which will be opened for this purpose. Approxi-

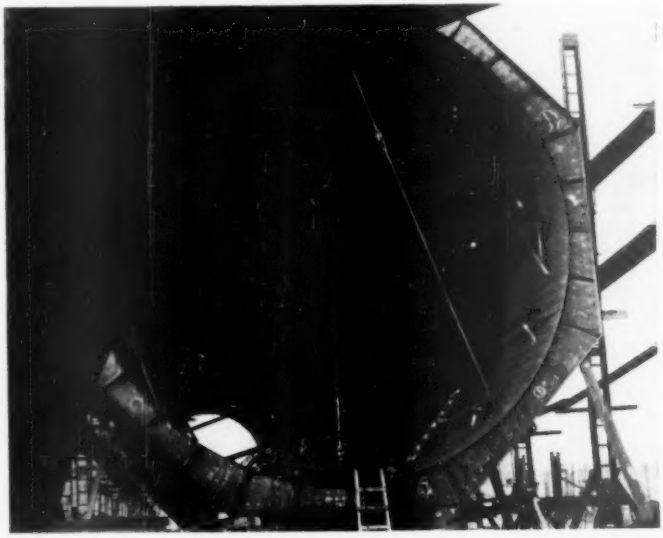

Fig. 4 Interior view of tunnel tube section on ways

Fig. 5 View of stud welding being done on sub-assembly

Fig. 6 Section on ways ready for launching

nately 900 tons of ballast concrete will then be poured inside the form plates.

Field Erection

The section will then be prepared for a 400 mile water journey through the Gulf of Mexico from Ingalls shipyard at Pascagoula, Miss., to Pasadena, Harris County, Tex., near where the tunnel will be located.

Upon arrival there, the interior concrete and portions of ballast concrete between shells will be placed, after which the section will be moved over a dredged trench and sunk into position to proper line and grade by pouring additional tremie concrete between shells. Masts will project above the water for guiding sinking operations.

The Sections will be connected to each other in their final location; the remaining concrete, between shells, will be placed by the tremie method and the trench backfilled to original grade. This backfill will be a maximum of 5 ft. above the top of the tunnel. To this grade, from the surface of the water, will be a depth of 45 ft. at normal tide. The bottom-most point of the tunnel will rest approximately 85 ft. below the surface of Houston Ship Channel.

Before removal of bulkheads and after all tunnel sections have been sunk in their permanent locations, they will be joined together. The joints are a series of saddles, pilot pins, locking pins, links and rachets which draw the steel rings to equal pressure against a gasket enclosed in a steel jacket to make the joints watertight. Steel channels will be welded on the inside of each two tubes so joined, over the joint between them.

The North and South sections will join transition sections, a new departure for this type of tunnel construction, which are already embedded in concrete (Fig. 7). These new additions permit work on the tunnel without the use of coffer dams.

The joints of the tunnel sections consisting of pilot pins, pilot pin guides, lock pins, links, rachets and gaskets are a part of all end connections of all tunnel tube sections. All steel members comprising the joints are so installed and welded in place, so as to remain at a perpendicular position when sections are placed at a 6% grade. The tunnel sections when joined will drop at a 6% grade from both the south and north end to approximately 50 ft., at which point the tubes level off.

After the tunnel sections have been joined and the tremie concrete placed and the backfill to the top of the tubes has been

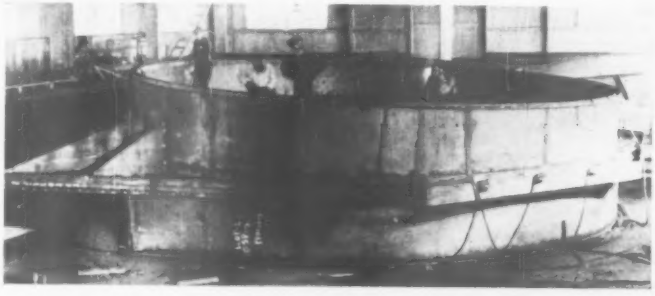

Fig. 7 Transition section under construction

Fig. 8 Section hit water during launching

completed, the bulkhead sections, in sequence, starting at the south end of the erection, will be removed. This phase of the operation opens all sections into one continuous tube. Now all is in readiness for the lining of the tunnel with tile and other materials.

Steel beams will cross horizontally to support the roadway to be constructed of reinforced concrete about one-third of the distance above the base of the tube.

The double lane roadway and approaches marking the entrance to the north and south end of the tunnel will be reinforced concrete with a vitreous lane marker between grade points. The tunnel will be lined with vitreous, glazed tile set in mortar.

At the south end will be located a four story ventilation building, two floors above the water line and two below to the tube.

This will be of structural steel frame encased in concrete and brick and natural stone. Floors and roof top will be of reinforced concrete slabs. In the building will be housed the necessary machinery and equipment to provide perfect functioning of this large underground vehicular tunnel, such as generators, ventilation fans, motors, etc. There will be electrical power, telephone, ventilation, fire fighting and safety facilities throughout the tunnel.

Traffic will pass through concrete arch sections and open ramps at the north and south ends which have been constructed of reinforced concrete. When the entire project has been completed the Pasadena Tunnel will open traffic movement through the steel and concrete artery south from Shaver St. to Federal Road at the north end.

Open-Circuit Voltage of A.-C. Arc Welders

This article answers many questions concerning the open-circuit voltage of A.-C. welders which constantly confront the welding engineers and operators. The influence of open-circuit voltage on the design and performance of A.-C. arc welders is given

by S. Oestreicher

THE open-circuit voltage of a.-c. arc welders has been reduced consistently during recent years. The gradual reduction was made possible by the development of special electrodes for a.-c. arc welders which provided arc stability and other performance characteristics formerly achieved only with d.-c. arc welding.

In the following a few simple and simplified relationships are used to point out the influence of the open-circuit voltage on the design and performance of a.-c. arc welders.

The primary and secondary current values of a transformer, neglecting the magnetizing current, are given by:

$$A_1 \times T_1 = A_2 \times T_2 \qquad (1)$$

where

A_1 = primary amps.
T_1 = number of turns of primary winding
A_2 = secondary amps. or welding current
T_2 = number of turns of secondary winding

The primary current therefore is:

$$A_1 = A_2 \times \frac{T_2}{T_1} \qquad (2)$$

and because the voltages under no load are approximately given by the relationship of the number of turns, or

$$\frac{E_{\text{primary}}}{E_{\text{secondary no load}}} = \frac{T_1}{T_2} \qquad (2a)$$

we have

$$A_1 = A_2 \times \frac{E_{\text{secondary no load}}}{E_{\text{primary}}}$$

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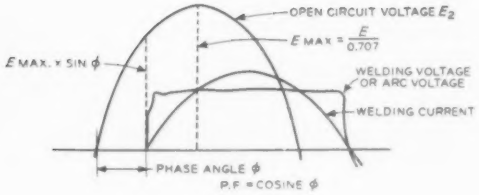

Fig. 1

Reducing the secondary no-load voltage or open-circuit voltage, therefore, reduces the primary current in direct proportion. The secondary coils are smaller for the number of turns is reduced with the reduction of the open-circuit voltage. The primary coils can be wound with a reduced wire size because of the correspondingly decreased current.

From the standpoint of the manufacturer, the lowest open circuit allows the most economical design.

Comparing two 220-v., a.-c. arc welders for the same output of 300 amp., but with 65 or 75 v., open-circuit voltage will give the following values, again neglecting the magnetizing current:

$$A_1 = A_2 \frac{E_{\text{secondary no load}}}{E_{\text{primary}}}$$

$$= 300 \times \frac{65}{220} = 88.5 \text{ amp. for the 65-v. machine,}$$

and

$$= 300 \times \frac{75}{220} = 102 \text{ amp. for the 75-v. machine.}$$

These welder current values are the corresponding line currents if no power factor correction is provided.

The open-circuit voltage determines also the power factor of the welding machine. For simplicity the losses are neglected in the following:

The kw. output is given by:

$$\text{Kw.} = E_{\text{arc voltage}} \times A_2, \qquad (3)$$

the kva. input by:

$$\text{Kva.} = E_{\text{primary}} \times A_1 \qquad (4)$$

and substituting the A_1 value given in (2a) results in

$$\text{Kva.} = A_2 \times E_{\text{secondary no load voltage}} \qquad (5)$$

or

$$\text{P.F.} = \frac{\text{kw.}}{\text{kva.}} = \frac{E_{\text{arc voltage}}}{E_{\text{Secondary no load voltage}}}. \qquad (6)$$

The two machines considered above therefore would show, at a 40-v. load:

$$\text{P.F. 65-v. machine} = \frac{40}{65} = 0.615$$

$$\text{P.F. 75-v. machine} = \frac{40}{75} = 0.533$$

The efficiency of these machines is about 0.85, and the actual P.F. is correspondingly higher, i.e., approximately

$$\text{P.F.} = \frac{0.615}{0.85} = 0.722 \text{ for the 65-v. machine}$$

and

$$\frac{0.533}{0.85} = 0.627 \text{ for the 75-v. machine.}$$

The power factor gives the phase angle between line voltage and line current and therefore also between open-circuit voltage and welding current. (The arc voltage is in phase with the welding current.)

Figure 1 shows the general relationship between welding current and open-circuit voltage. If the arc is extinguished at the point of zero welding current, the voltage value $E_{\max.} \times \sin \phi$ is available for restriking the arc. Therefore, it can be seen that a certain phase shift is necessary for good welding performance. With an ideal P.F. = 1, $\phi = 0$ or no phase shift, the restriking voltage value is zero ($E_{\max.} \times \sin 0 = 0$). The best restriking condition would be at P.F. = 0 or a phase shift of 90°, for $E_{\max.} \times \sin 90 = E_{\max.}$. This condition would demand an extremely high open-circuit voltage (see Equation 6) or some other means of phase shifting.

The "restriking voltage" values for our examples are easily calculated. The 65-v. machine shows approximately:

$$\text{P.F.} = 0.722, \phi = 43.8°, \sin \phi = 0.692$$

and

$$E_{\text{restriking}} = \frac{65}{0.707} \times 0.692 = 63.5 \text{ v.}$$

For the 75-v. machine the corresponding values are:

$$\text{P.F.} = 0.627; \ \phi = 51.3°; \ \sin \phi = 0.779$$

and

$$E_{\text{restriking}} = \frac{75}{0.707} \times 0.779 = 82.5 \text{ v.}$$

The increase of the open circuit by 15% (from 65 to 75 v.) increases the restriking voltage by 30% (from 63.5 to 82.5 v.). For performance, therefore, the machine with higher open-circuit voltage and lower power factor will be advantageous.

The designer has to select the values that will be best suited for the application. Each design will be a compromise considering economy of material and labor which demand low open-circuit voltage, and performance which indicates the higher voltage values as desirable.

(*Continued from page 352*)

be referred to any particular current reading in relation to Fig. 11. The humidity values were also different.

With regard to the double short circuit phenomena, the high-speed movies do not indicate premature rupture of the short circuit. It is possible, however, that the premature rupture may have some bearing on the behavior. This has not as yet been investigated.

Stress Corrosion in Naval Brass Weldments

Naval Brass Weldments are subject to stress corrosion unless stress relieved. Suitable stress-relief treatment is indicated

by Bela Ronay

IN THE Fall of 1941 two Battleship Class Naval vessels were being fitted out in two East Coast Navy Yards. Each of these vessels was equipped with batteries of salt water evaporators. The elements of these batteries were 6-ft. diameter shells, 6 ft. long, made of $^{5}/_{16}$-in. thick half hard Naval Brass procured in accordance with Bureau of Ships Specification 46B6 (INT). These shells were fabricated about 18 months prior to the above period by arc welding using phosphor-bronze electrodes. Fabrication included, in addition to the attachment of the flanges, affixing internal brackets which carried the tube bundles. On completion of the installation at both yards, the shells were tested by hydrostatic pressure at 50 psi. In both installations this test revealed the presence of cracks emanating from the ends of the fillet welds which joined the brackets to the inside of the shells. Prior to installation, these welded shells had been stored for approximately 18 months in the open, adjacent to the fitting-out piers.

The discovery of the cracks produced two problems, namely, that concerning the applicable method of repairing, and the precautions necessary to prevent crack development in evaporator shells then on order or whose production was projected for the immediate future.

This paper concerns an investigation performed with the following objectives: (*a*) Determine the cause of the cracks and (*b*) in the event it is established that crack development is directly attributable to the welding procedure employed, develop preventive methods.

Chemical analyses were performed for samples removed by trepanning, from the defect zones to determine whether the crack development could be attributed to lead content in excess of the values given in the applicable specifications. The result of this examination was negative. Microscopic examination of transverse sections of the trepanned specimens showed that the cracks were intergranular and had the earmarks of stress corrosion failure. The crack shown on the photomicrograph, Fig. 1, is typical for the defects which occurred in these shells. Based upon the results of this examination it was decided to investigate whether the crack development was attributable to the welding procedure and, if that was the case, modify the welding procedure to prevent recurrence of stress corrosion. The objective of the first phase of the investigation was the quantitative determination of the residual stress developing in a weldment comparable to the defective structures concerned. For the purpose of this investigation a stiff frame assembly was fabricated whose details are shown on Fig. 2.

The Naval Brass plate used measured $^{5}/_{16}$ x 30 x 32 in. The hardness of the Naval Brass stock used averaged 67.8 Rockwell "B" scale for both the finished surface and the sectioned polished face. The method of assembling the subject stiff-frame unit is seen on the photograph, Fig. 3. Accordingly, the entire surface of the brass sheet was water-cooled during the deposition of the tie-in joints, with the exception of a 4-in. band beyond the heated zone. The water dam shown on the photograph was backed up by a clamped-on angle iron which was relocated for each tie-in joint. The joints were made using manganese-bronze welding rods deposited as shown, by oxyacetylene welding. After the last tie-in joint cooled to room temperature, the bracket, whose details are shown in Fig. 2, was placed in position and welded on.

The first joint between clip end No. 1 and the plate was welded without preheating, using $^{3}/_{16}$-in. diameter phosphor-bronze electrodes at a current rate of 210 amp. Clip end No. 2 was welded immediately after clip end No. 1.

Plastic deformation of the weld zone was determined by measuring the displacement of the grid lines which are shown on Fig. 2. These grid lines were scratched on the plate subsequent to welding it in the frame. The grids, 0.10 in. square, were applied on a milling machine. Displacement of the ordinates of the grid was measured by means of an optical extensometer mounted on a subbase equipped with a compound micrometer adjustment. The results of this examination are shown on Fig. 4. On these diagrams the abscissae and the ordinates are presented in 1:1 and 2:1 ratios, respectively; the deformation is indicated on the enlarged scale of 200:1 ratio. The maximum deformation which occurred at the No. 1 clip of the bracket at the region of abscissa No. 25 was 0.0085 in. Four inches beyond the

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The opinions expressed in this paper are those of the Author and do not necessarily coincide with the official views of the Navy Department.

above zone along the base line abscissa marked No. 5 the deformation averaged only 0.0005 in. Deformation values obtained for the area surrounding clip No. 2 are comparable to those given above. It was noted, however, that while for clip No. 2 the whole area between abscissae numbers 5 and 20 was in tension, the area of the grid below abscissa No. 5 of clip No. 2 was in compression.

As measuring the plate thickness was impracticable, determination of the elastic residual stress within the zones affected by the plastic flow was restricted to only two components. For the purposes of this determination, four $^1/_4$-in. diameter hexagonal head screws were tapped into the plate in locations shown on Fig. 2. A $^1/_8$-in. diameter hardened steel ball was then inserted into one face of each of the hexagonal heads. The screws, tightened into the plate by means of shims, were so arranged that Nos. 1 and 3, and 2 and 4, respectively, were set with the balls located opposite and facing one another. Then the distance between the above given pairs was measured by means of a telescopic micrometer. Subsequently, the area indicated on the drawing on Fig. 2 was removed by milling, which was performed at a slow rate of feed in order to prevent the development of additional stresses. This relaxed portion of the plate contained the already calibrated distances which were again remeasured.

The results of the measurements were as follows:

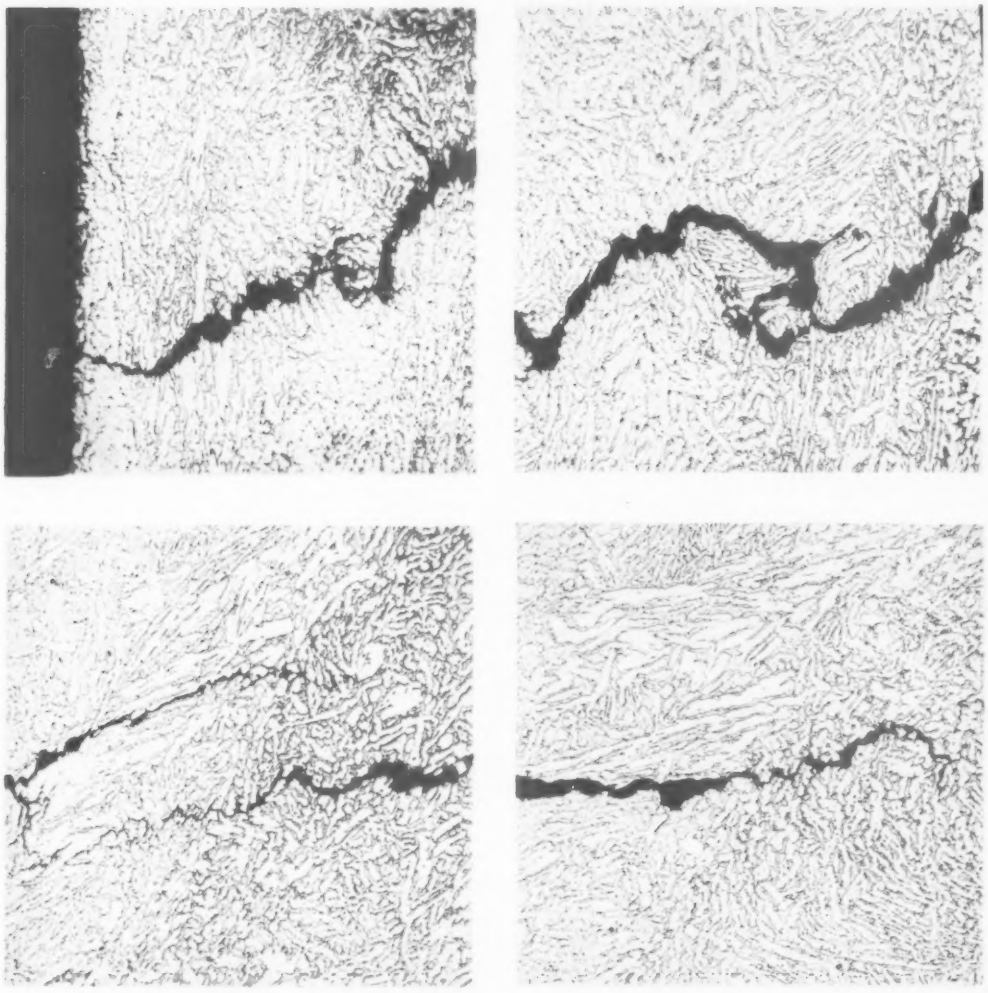


Fig. 1 Typical stress corrosion cracks

Direction of stress	*Strain, in./in.*
Axis A-A	0.00036
Axis B-B	0.00182

NOTE: Axis A-A denotes the transverse axis through the bracket; Axis B-B is perpendicular to it.

The stresses resulting from the above given strains were computed on the basis $S = (e \times E)/m$, where e is the unit strain, E = 15,000,000 psi., the modulus of elasticity, and $1/m$, Poisson's ratio, is 0.33.

The computation for the two stresses gave the following results: $S1$ (Axis A-A) = 1800 psi.; $S2$ (Axis B-B) = 9100 psi.

The above results indicated the need for a stress-relief treatment and therefore the next phase of the investigation concerned the determination of the applicable stress-relief procedure. The method employed for this determination was based on the following concept:

A freely suspended, centrally loaded beam recovers fully the deflection which obtains during load application, provided the value of the extreme fiber stress during loading is below the yield point of the material of the beam. The above statement pertains to all conditions in respect to beam temperature. Another consideration is that with increasing temperature, the yield point and the modulus of elasticity of metals becomes depressed. Consequently, a given load which develops a stress value considerably less than the yield point of a metal at room temperature will produce in that beam a stress in excess of the yield point in the event the temperature of the metal is elevated to depress the yield point to the corresponding degree.

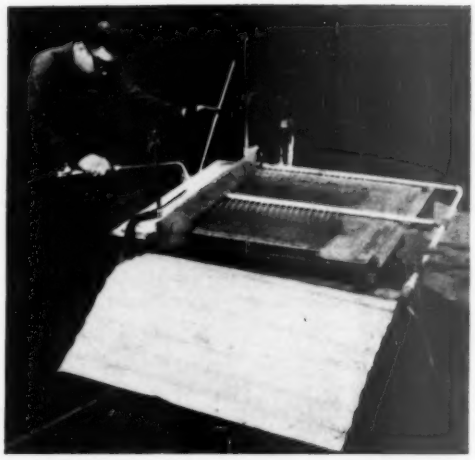


Fig. 3 Welding to the stiff frame, with water cooling of the test portion

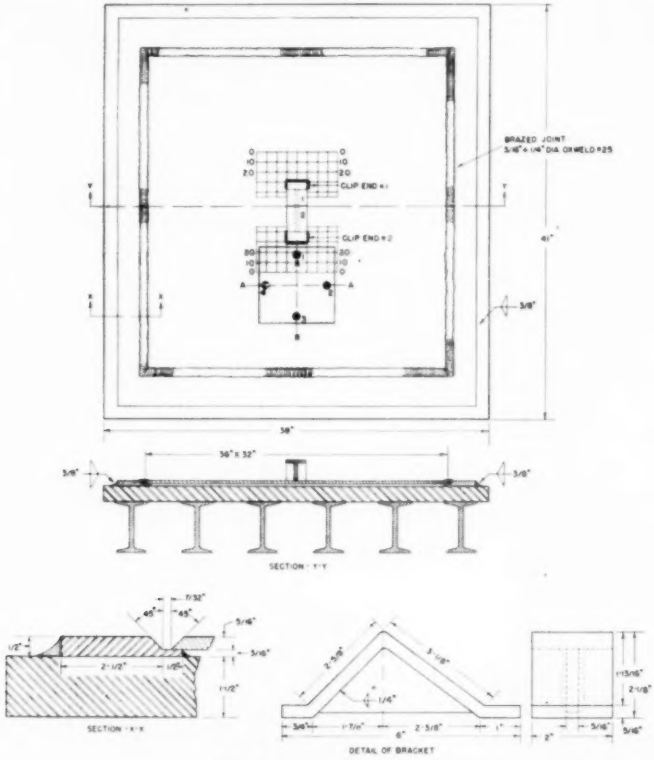


Fig. 2 Stiff frame assembly

Based on the above considerations the following test procedure was designed to determine the applicable stress-relief temperature for Naval Brass weldments:

The equipment used for this determination is shown on Fig. 5. It consists of a stand to support the specimen which is a beam of rectangular cross section usually 0.30 x 0.40 x 11 in. This stand is equipped with a loading device to produce central loading on the freely suspended beam specimen. The specimen is heated by a loosely coupled coil energized from a source of high-frequency current. The beam is insulated for its full length and carries a thermocouple imbedded in the upper surface near the center. The procedure employed consists of loading the beam to develop a fiber stress of 2000 psi., heating to a predetermined temperature, holding that temperature

for a prescribed period, and then cooling to room temperature. Then the beam is removed and applied to the measuring stand to determine whether a permanent deformation was obtained. The above procedure was applied successively for beam temperatures of 550, 600 and 700° F., respectively. The latter temperature gave a permanent deformation of 0.1875 in. after a two-hour heating period.

The third phase of the investigation was based on the information obtained from the above determination as regards the stress-relief treatment. To evaluate that information the following were performed. Thirteen $^5/_{16}$-in. thick Naval Brass plates of 30 x 72 in. were rolled to form 22 in. diameter cylinders. These plates were procured from the sources which furnished the material for the evaporator shells, and were comparable in regard to chemical composition and hardness. These cylinders were $^1/_3$ size replicas of the original evaporator shells. The longitudinal seams of these cylinders were welded by gas welding using manganese-bronze welding rods. Within these cylinders, clips were attached as in the prototypes, by arc welding, using phosphor-bronze electrodes. The various preheat and postheat temperatures employed which ranged from none to 400° F. and none to 750° F., respectively, are shown on Table 1. The shells were subjected to hydrostatic pulsations which developed a hoop stress of 11,000 psi. for each cycle at 40 pulsations per minute. This test cracked many of the longitudinal welds but no

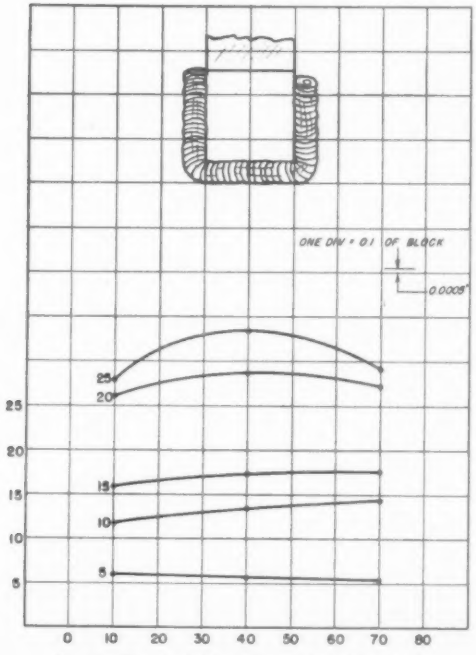


Fig. 4 Plastic deformation below Clip No. 1

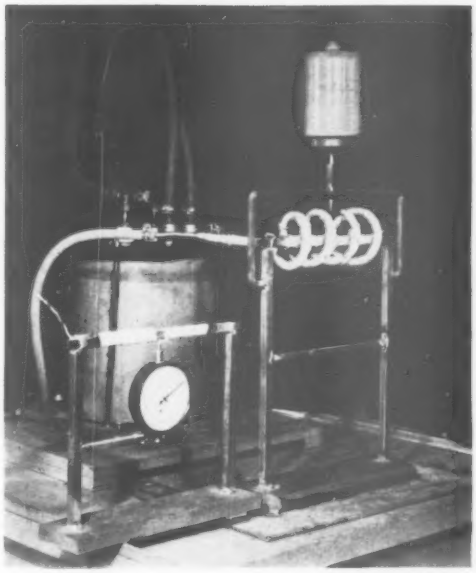
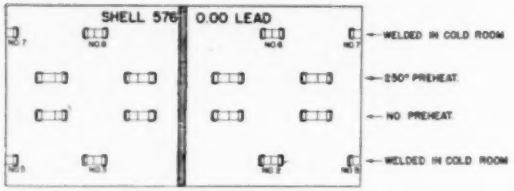


Fig. 5

cracks developed at the weld zone. Subsequently, the weld zones of the shells were given a mercurous nitrate treatment using a 1% solution of mercurous nitrate which contained 1% nitric acid. The results of this test are shown in Table 1. This table shows variations of the lead content of the plates used, the effect of the various preheat levels and of the 750° F. postheat treatment. On completion of the above test, the cylinders were put in outdoor storage. Nine months later those which in the first application of the mercurous nitrate treatment were found free of defects in the bracket zone were given the same treatment as before, maintaining the treatment for each for a period of four hours. This treatment was repeated for six consecutive days. From these tests only those given the postheat treatment at 750° F. emerged crack free. On the basis of the above investigation the defect development found in the evaporator shells was identified as stress corrosion. The phenomenon stress corrosion is defined by W. Lynes as given in the *Proceedings* of the A.S.T.M., Vol. 41, 1941, as follows: "Intergranular Cracking—Many metals and alloys fail from intergranular stress-corrosion cracking under suitable combinations of static stress, corrosion and temperature. Among these are: various steels, aluminum and alloys, nickel-copper alloys and various brasses and bronzes (especially the higher zinc brasses, aluminum brass and bronze and silicon bronze)..... The requisite environmental conditions vary from alloy to alloy, but the corrosive attack when produced is characterized universally by selective pitting and grooving of the grain boundaries. Stated electrochemically, the grain boundary is anodic to the grain. The notch

Table 1.

DEVELOPMENT OF SHELLS IN WHICH SEASON CRACKS FORMED NEAR THE WELDED CLIPS

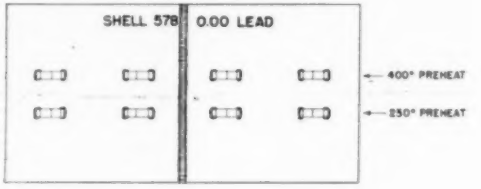


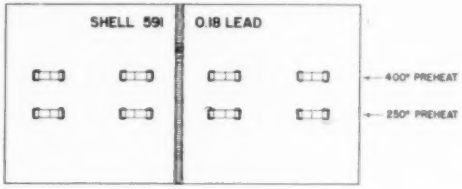
EFFECT OF LOCAL PREHEAT

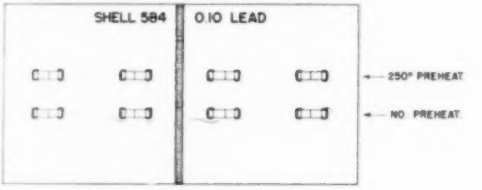
LOCAL PREHEAT	LEAD CONTENT	NO OF CLIP ENDS	NO OF CRACKS	RATIO CRACKS/CLIP ENDS
NONE	.17 - .19	16	3	.19
	.10 - .11	16	4	.25
	NONE	28	2	.07
250°F	.17 - .18	24	4	.17
	.10 - .11	24	2	.08
	NONE	24	1	.04
400°F	.17 - .18	8	0	0
	.10 - .11	8	0	0
	NONE	8	0	0

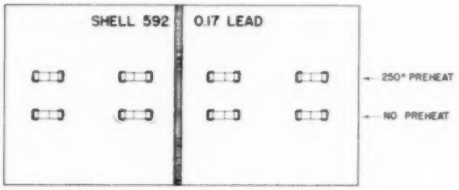
EFFECT OF POST HEAT

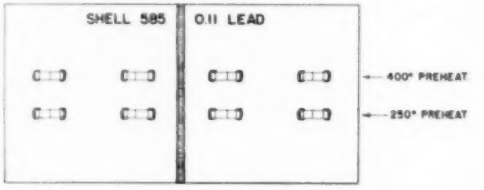
SHELL NO.	LEAD CONTENT	POST HEAT	NO OF CLIP ENDS	NO. OF CRACKS
582	0.10	750°F	16	0
584	0.10	NONE	16	4
591	0.00	750°F	16	0
576	0.00	NONE	28	2

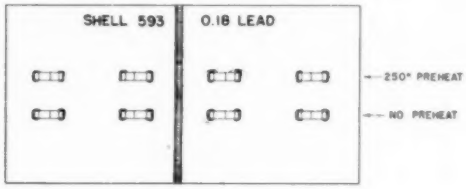












effect of grain boundary corrosion together with pressure developed by any corrosion products lodged therein eventually superimpose a damaging stress concentration on the stresses existing previously. Thereupon cracks are propagated along the grain boundaries..... This type of attack on brasses and bronzes inaptly is called 'season cracking.' Its occurrence in stressed brasses or bronzes is favored particularly by contact with aqueous solutions of ammonia or compounds of ammonia or mercury or by mercury itself. The season cracking of stressed brass or bronze on atmospheric exposure depends on slight concentrations of ammonia or other accelerants in the air and the presence of moisture at the surface of the metal. Under these feebly corroding conditions, the period required to produce failure is sometimes measurable in terms of months or years; hence, the term 'season cracking.' When this terminology was proposed, the influence of corrosion had not been recognized; but, in view of present knowledge, 'stress-corrosion' more completely would define the phenomenon."

Conclusions

From the performance of the above investigation it is concluded that restrained portions of Naval Brass weldments fabricated by arc welding are subject to stress corrosion unless stress relieved. The investigation further showed that in restrained Naval Brass weldments residual stress of 9000 psi. in tension is reached in the direction of the weld. The investigation further showed that preheating alone, even though the preheat temperature of 400° F. is employed, is insufficient to prevent stress corrosion. Finally, from this investigation, it is also evident that a postheat treat-

ment at 750° F. maintained for a period of not less than an hour and a half for each $^1/_2$ in. of the material followed by cooling to 250° F. and at the rate of maximum 150° F. per hour prevents stress corrosion regardless of the preheat temperature employed in course of fabrication.

Recommendations

On the basis of the above findings the following recommendations were made concerning fabrication of Naval Brass by arc welding using phosphor-bronze electrodes: (*a*) preheat the weld zone to the minimum of 400° F. and (*b*) stress relieve the weldment at 750° F. holding it at that temperature for an hour and a half for each $^1/_2$ in. of wall thickness. Cool in furnace to 250° F. at the rate of maximum 150° F. per hour.

Discussion

The methods employed in the course of the above investigation appear at this date somewhat outmoded. In performing similar investigations underway at present for other nonferrous materials, the grid is developed by photographic methods and the measurement for the elastic stresses is performed using short and long gage mechanical strain gages which are augmented in certain locations by single and multiple SR-4 type electrical strain gages. The above given instrumentation is expected to yield a pattern of the distribution of the residual stress comparable to that obtained for the plastic deformation.

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(*Continued from page 328*)

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Code Inspection on Welded Pressure Vessels

Some of the considerations which the office of the code inspector of welded pressure vessels must face are briefly outlined

by Floyd F. Johnson

SHOP surveying, commonly called "Shop Inspection," and what it means as related to pressure vessels will be briefly outlined. In this age of acute engineering, keen competition, multitudinous materials, safe employment, safe place of employment and endless variety of application, the surveying of shop procedures and practices and determining of acceptable materials for given or desired uses has assumed major aspects, and is of vital import.

Not so long ago, pressure vessels usage was concerned with steam boilers, compressed air receivers and, in not too great an extent, containers for a few of the vehicles concerned with refrigeration. Today it is vastly different—now we have an endless variety of contents and uses for pressure vessels.

We are not only concerned with the matter of pressures, but we have to contend with extremely high and/or low temperatures, mild to acute corrosive action, peculiar material behavior under shapeworking and heat effects during construction procedure as well as estimated effects in use.

Fortunately, there is a considerable amount of built up and recorded experience on materials, design, construction and utilization from which can be drawn useful information to cover most any situation, or such can be used as a basis on which to design.

In surveying a project of pressure vessels, the first and important step is the examination of the drawings and specifications, for determination of compliance with applicable codes, rules and orders.

Next is the determination that the fabricator's facilities are ample for the work to be undertaken. Then, determine that he has set up procedural qualifications for the work, and that he has the necessary registrations and agreements with authoritative agencies, to proceed.

When the foregoing has been determined, the next step is the examination of the material to be used.

This encompasses the securing of the mill stamping on the material and checking against the mill test reports for verification and acceptability; then observe that the cutting, shaping, fit-up and shop procedures are in compliance with specified regulations. Then follows shop test, mostly by hydrostatic pressure, but occasionally by other means. When the project has successfully met the foregoing, the applicable symbols and/or stamping may be applied. After which, when properly installed, fitted and surveyed, such pressure vessel is safe to be used, within the limitations as set forth in the stamping.

Mild steels are the most common used for pressure vessels, and are not difficult to handle within normal use ranges; viz., atmospheric temperature and internal pressures up to limit of permissible stresses, but when elevated temperatures (above 650° F.) are encountered, allowances must be made in accord with permissible stresses at the respective temperature ranges; likewise low temperatures (−40° F. and lower) require special attention.

Varied materials call for special consideration. High tensile steels require special treatment during fabrication—some can only be formed hot and some at merely warmed up condition. In welding fabrication, alloy steels need special attention, preheat, postheat and electrodes of comparable physical and chemical composition. The stainless steels are the most peculiar—especially with regard to intergranular behavior under heat treatment and fabrication procedures.

While nonferrous materials are, as yet, not in extensive use for pressure vessels, aluminum is attaining some considerable attention.

The types of fabrication, likewise, vary. The old riveted construction is very little used now. Welding is by far the most common. There is also a considerable amount of so-called copper brazing, which, however, is limited to a use temperature of 406° F.

Seamless drawn, with integral heads, is also quite popular, within practical dimensions.

It is the office of the Code Inspector to determine that all requirements have been complied with, that the materials are Code acceptable and that all techniques are within the limits prescribed.

Floyd F. Johnson is a Boiler Safety Engineer with the Division of Industrial Safety, State of California.

Techniques for Auto Body and Fender Brazing

New procedures are described that cut costs and broaden the field of application. Inexpensive repairs are made when former methods would not be practical.

by Carl E. Jacobs

A TIME saving of about 70% on the general run of welding repairs to auto bodies and fenders and an over-all cost saving of 25 to 40% were obtained in one body shop during twelve months of operation as the result of adopting new brazing procedures. Also it was found that relatively inexpensive repairs could be made in many cases where former methods would not have been at all practicable and the purchase of costly new parts would have been necessary.

Many body shops avoid brazing because of the need for thorough mechanical cleaning of the parent metal adjacent to the braze, both before and after the operation, and also because brazing in the vertical and overhead positions is so difficult. In these shops, fusion welding is used to the greatest extent possible, though it has the disadvantages of causing more distortion, of leaving a hardened area alongside the weld and of making leading jobs more difficult. There are many expert welders in the business, both gas and electric, who can make a splendid repair on thin sheet metal. However, there are numerous jobs which they turn down as impracticable because of the presence of rust and the thinness of the metal. This article concerns new procedures that not only cut costs but also broaden the field of application in body and fender work.

These new procedures, which are quite easy to apply, involve the use of the Gasflux-brazing process. The flux is not applied separately, but is held in liquid form in a container through which the acetylene or other fuel gas passes, so that the stream of fuel gas automatically picks up a sufficient quantity of the flux and delivers it to the work in the flame. The fluxing action is continuous, uniform and controllable, and there is no adhering residue to be removed.

The apparatus is simple and easy to hook up in the fuel line. For the average service station or body shop, a convenient way is to weld a small shelf to the rear of a conventional two-cylinder gas welding hand truck and mount the unit, complete with reserve tank, on this shelf. The acetylene hose connects to the inlet valve of the Gasfluxer and the torch hose leads from the gas outlet valve to the acetylene valve on the torch. A by-pass valve permits shutting off the flux entirely so that the torch may be used for regular welding without disturbing the hook-up.

One procedure has been developed for applying a bronze overlay to badly rusted spots or areas, such as are found along the bottom edge of a fender or door, or along the seam between fender and body. The rebuilding of such areas is seldom attempted by ordinary welding and brazing methods, but it is not at all difficult when the flux is carried in the flame. Assume the metal to be so badly rusted that the sound metal remaining is only paper thin. Grinding or wire brushing to remove the scaly oxide would crush and collapse what little metal remains. But if only the smallest amount of the original metal is intact, full thickness and strength can be restored.

A small sheet metal welding torch, any standard make, fitted with No. 0 or No. 1 tip, is used. The flame is first adjusted to be strongly oxidizing. To remove the rust and scale, this flame is held nearly horizontal over the rusty area and blows across it, instead of being directed straight against the surface. The scale and surface oxides are lifted away and the sound metal below is quickly heated to brazing temperature. Then the oxygen flow is reduced so as to produce just a slightly oxidizing flame, for the build-up. Brazing material is $^{3}/_{32}$-in. low-fuming bronze rod.

Best procedure is to start tinning at an edge, then flow on the bronze, leading the flame with the rod and holding both flame and rod at an angle of about 30° with the surface. It isn't necessary to poke or work the bronze into holes and porous spots, because the ever-present flux in the flame causes it to flow in and fill them with clean, sound metal.

Important features of this procedure are: (1) correct flame adjustment for both steps; (2) using the side of the flame for scale removal; (3) starting the tinning at an edge. The effect, when properly executed, is a strong, smooth overlay of bronze, which can be dressed down and finished so perfectly that the repair cannot be detected after painting.

A second procedure has been developed for brazing

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square butt joints, as in repairing a crack or inserting a patch flush with the fender or body surface. In most of this work it is extremely difficult to clamp the work properly in alignment without doing an extensive dismantling job. An important feature of this new procedure is that alignment is secured as the work progresses and without the use of clamps.

Take the case of a fender crack extending in from the edge toward the body. If the fender has been crushed, it is first smoothed out with hammer and dolly block so that the surfaces can be lined up all along the crack. The same torch and brazing rod are used as for the overlay. The flame is adjusted to neutral, directed straight at the surface and held quite close to it. When heating starts, the flame is rotated in a small circle centering on the end of the crack. This heats and fuses the edges and forms a small pool of molten metal. The tip of the inner cone of the flame is then directed at the center of the pool and brought closer, until it pierces a hole through the sheet at the end of the crack—making sure that the crack actually stops in the hole. A sharp hiss signals the break-through and the torch tip is quickly drawn away. This leaves a collar of steel protruding slightly on each side of the sheet—the equivalent of a hollow rivet, only stronger.

Manipulating the work with one hand so as to keep

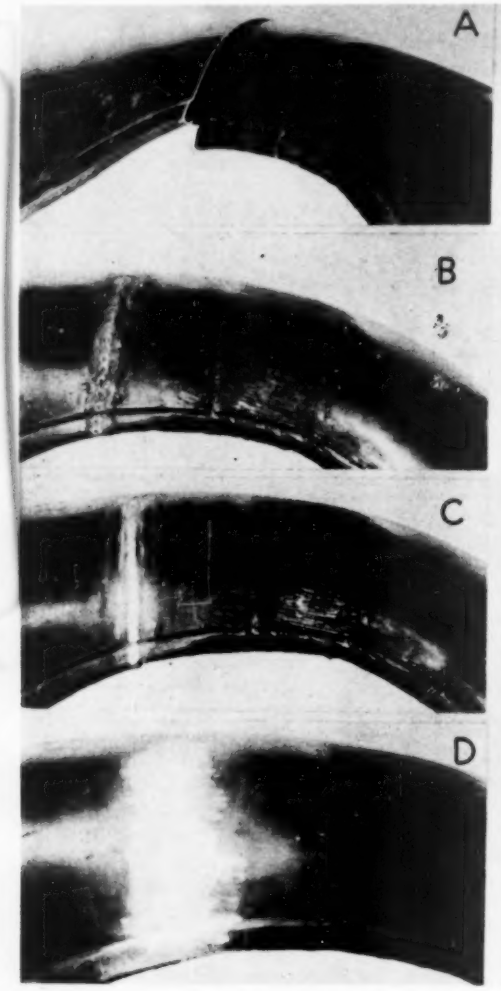


Fig. 1 Brazing seam in fender

(A) Badly cracked fender to be repaired. (B) Crack aligned and tacked with "hollow rivets." Note rusted spot at right in center of fender, which has been repaired with a bronze overlay. (C) Brazing of crack completed. (D) Fender finished down ready for paint

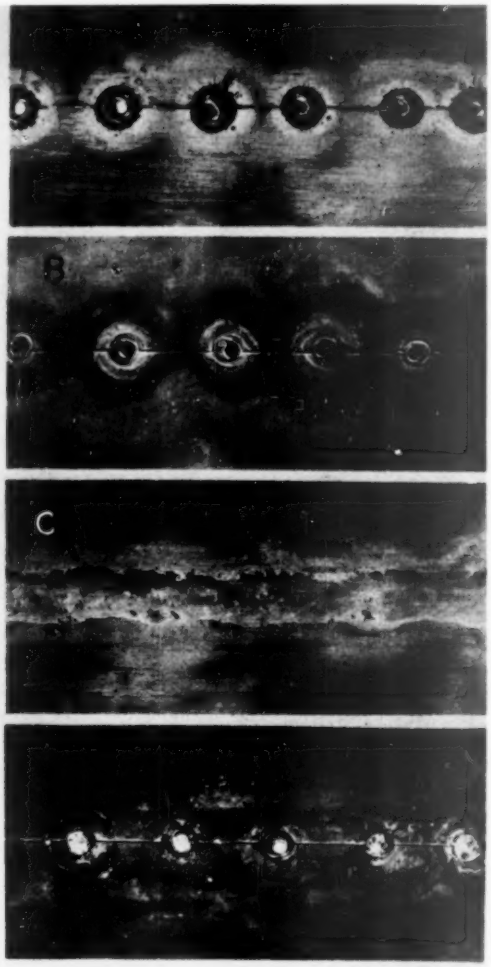


Fig. 2 Close-up "hollow rivet" procedure

(A) Seam tacked with "hollow rivets," front side. (B) Rear view of same. (C) Brazing completed on front side. Note smooth deposit and even bonding. (D) Rear side of same, showing bronze buttons that act as strong points

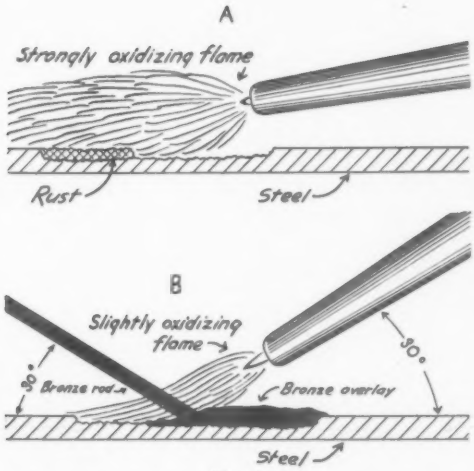


Fig. 3

(A) Flame cleaning rusted surface. Note that flame is strongly oxidizing and is held nearly parallel to the surface.
(B) Applying the bronze overlay. Flame is slightly oxidizing. Start tinning at edge of spot and work toward the center. The rod is low-fuming bronze

the crack closed and the surfaces aligned, a second hole is pierced, centered on the crack and about $1^1/_2$ in. from the first hole. This is repeated at equal intervals until the outside edge is reached. The crack is now aligned and tacked. However, enough heat may have been applied to distort the metal. This is soon corrected with the dolly block and hammer. Then additional holes are pierced all along the crack, in the spaces between those already made, about $^3/_8$ in. apart. Again a little more smoothing with the dolly block may be needed. It is now an easy matter to lay a bronze deposit along the line of the crack, using the conventional slightly oxidizing flame and leading the flame with the rod as previously described. The bronze will run through the "hollow rivets" and appear as small irregular buttons on the under side. When the bronze deposit is dressed down flush with the outside surface, these buttons on the under side become so many strong points.

The brazing in of large patches can be started by tacking with a "hollow rivet" at some convenient central point which will permit manipulating the patch so as to preserve alignment while the first series of tacking holes are pierced. Patching a small notch or a totally enclosed hole is just as easy. The patch is cut to fit flush in the hole. A small spot is heated near the center of the patch and one end of the bronze is fused to it. The rod now serves as a handle, to hold the patch in place while holes are pierced around the periphery. Then the bronze rod is melted loose and is used to braze around the patch.

Following is a summary of the advantages which have been observed where these procedures are properly applied to body and fender repairs:

1. The process itself is fast, and several time-consuming operations are either eliminated or greatly reduced, so that impressive savings are made.

2. No time need be spent in mechanical cleaning of rusty stock. The flame does a better job, faster.

3. There is a big saving in body lead, due to the small amount of distortion. Sometimes no lead is necessary. Fusion welded areas are subject to more distortion, need more careful cleaning before they will take the lead and at best do not take the lead so well as a bronzed surface. At prevailing lead prices the saving in lead is an important cost item.

4. Minimum distortion saves straightening and dressing time.

5. Low heat input avoids disturbance to the metal structure. There is no danger of leaving a hard brittle area in the adjacent parent metal.

6. The finished part is as strong as a new part, or stronger.

7. The process can be applied in the vertical and overhead positions.

8. An over-all saving of 25 to 40% is accomplished.

9. Many customers can be saved the high cost of installing a new fender.

10. The process is applicable to numerous repairs that it would be hopeless to attempt by any other method.

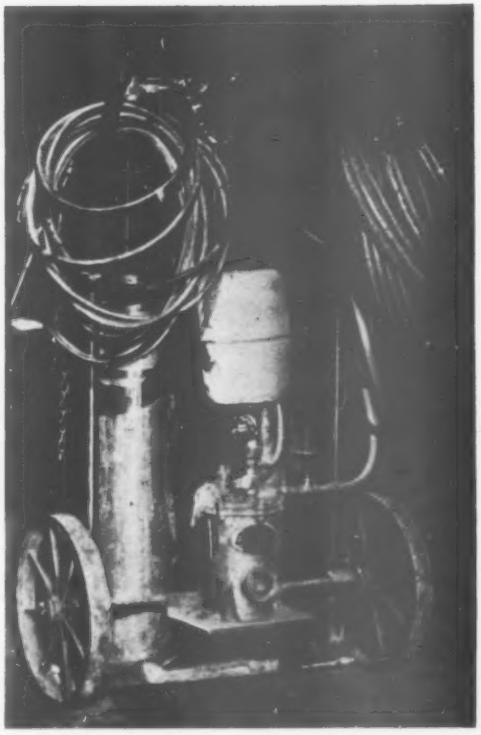


Fig. 4 Gas fluxer mounted on two-cylinder welding truck

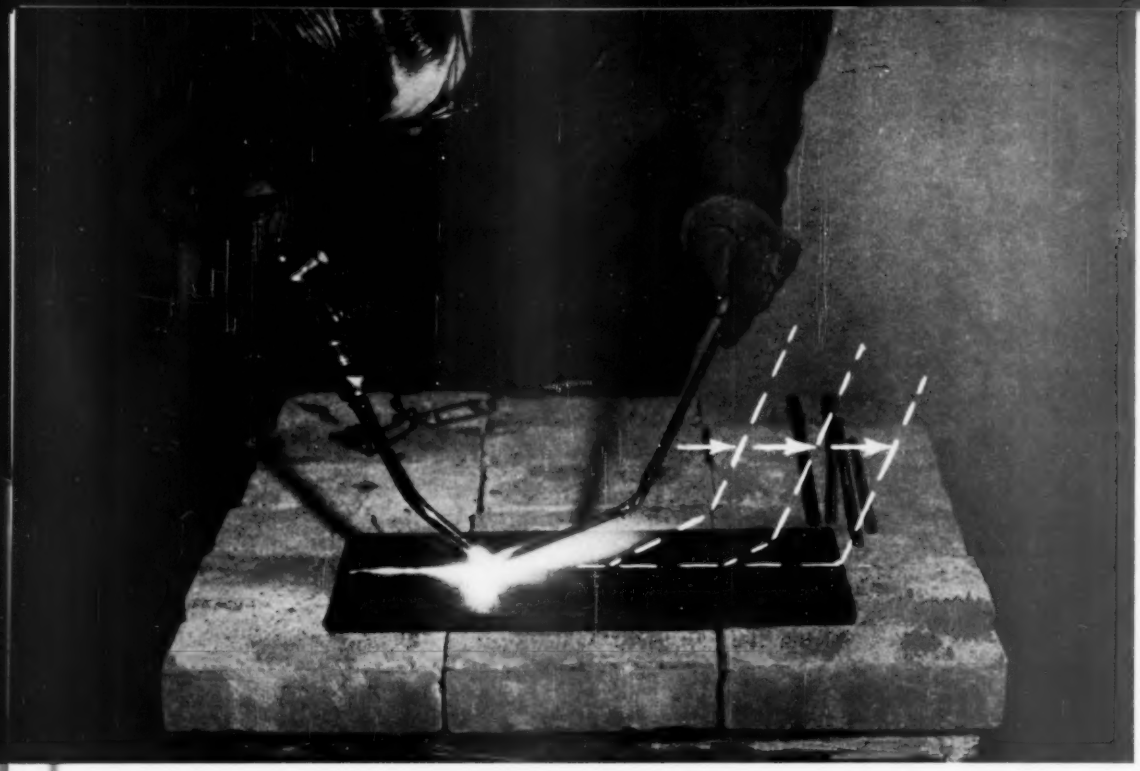


Fig. 1 Drawing out hard-facing rod to a smaller diameter rod is a simple operation. The broken lines show positions and motion of the rod during drawing

Hints for Hard Facing

by H. B. Gilson

CLEAN the part thoroughly. That is the most important step to take before you begin a hard-facing job. All rust, scale and other foreign material should be removed from the areas to be hard faced. Grinding, chipping or machining provides the best surface. If necessary, you can clean the surface with a file or wire brush. But this method often leaves some material which you must be sure to remove from the molten metal during the hard-facing operation. You can use your blowpipe, with a neutral flame, to preheat the casting to a temperature of about 500°. It is more economical to preheat large castings in a furnace.

HARD-FACING CAST IRON

When you hard face cast iron you will find that it does not sweat like steel. A little less acetylene should be used in the flame than for steel. (For steel the excess acetylene feather should be two times as long as the inner cone.) You will also find that the hard-facing rod does not flow as readily on cast iron as on steel. For that reason it is usually necessary to break the surface crust on the metal with the end of the rod. A cast-iron welding flux is necessary sometimes.

It is usually best to deposit a thin coating of hard-facing rod first and then go over the second time to build up to the desired thickness. Because this rod and cast iron have about the same melting point, you must take care not to melt the base metal too deeply. If the cast iron is very thin, back it up with wet asbestos or carbon paste to prevent the part from collapsing. On either steel or cast-iron parts use the same cooling procedures as you do for an ordinary welding job.

When you hard face small parts or areas you usually need a rod $^1/_8$ in. or less in diameter. Some shops buy these small diameter rods ready for use, while others prefer to "draw out" $^3/_8$- or $^3/_{16}$-in. rods. The most economical method for your shop depends on local con-

H. B. Gilson is with The Linde Air Products Co., Newark, N. J.

ditions, including local costs for oxygen, acetylene and labor.

The "drawing-out" operation is simple. First prepare a mold. A grooved plate of carbon, graphite, iron or steel makes an excellent mold. Or you can use length of angle iron. Adjust the blowpipe flame for an excess acetylene flame, just as you would do for a hard-facing job. Then direct the flame on the end of the $^3/_8$- or $^5/_{16}$-in. hard-facing rod. When it begins to melt, draw the rod away from the first drop at a steady rate. A thinner rod will be deposited in the mold, and it will be ready to use as soon as it cools.

Badly Fractured Cast-Iron Gear Box Repaired

by Donn Boring

ONE of the heaviest cast-iron repair jobs ever tackled in Canada with Ampco-Trode 10* aluminum bronze electrodes was recently completed by Montreal Welding Co., and is a credit to their skill and the product that made the success of the repair possible. The part involved was a Gear Box for a TD-18 tractor which houses the transmission, differential and steering mechanism.

Since the broken section was in two pieces the first step was to weld these pieces together, after which the remaining joints were chamfered to a 45° angle from both sides using a pneumatic hammer for the rough work and a grinding wheel to finish it off. Excess grease was burned off with a torch and the weld area was thoroughly cleaned with carbon tetrachloride. The job was then set up and clamped in position as shown in Fig. 2.

The casting was preheated to approximately 300° F. and this heat was maintained by a charcoal fire that was built under the casting. Once started, the welding had to be continuous in order to maintain the heat in the casting and avoid any cracking.

All outside welding was completed first and the welds were staggered to distribute the heat more evenly. Where the fit-up was poor, two passes consisting of a layer of $^1/_8$-in. electrodes and a finishing pass of $^3/_{16}$-in. electrodes were used. Where the fit-up was good, one pass with $^3/_{16}$-in. electrode was sufficient. All welding was done in the downhand position and after completing the outside, the casting was turned and the back of the joint was welded. Upon completion of welding all outside beads were ground smooth and appeared as shown in Fig. 3.

Aluminum bronze electrodes were selected for this repair job because the deposits are very dense and ductile, have a high strength-low yield ratio and produce a weld-brazed bond with low base-metal dilution. Therefore, weld and fusion-zone cracking does not occur in highly stressed assemblies where other electrode types have a tendency to fail.

Donn Boring is with G. D. Peters & Co. of Canada, Ltd.

Data supplied by Ampco Metal, Inc.

* A.W.S.-A.S.T.M. Specification ECu A1-A.

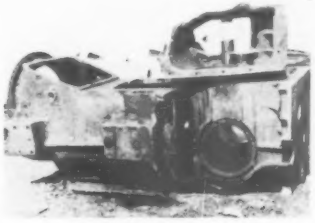


Fig. 1 Broken gear box before welding

Fig. 2 Method of assembly

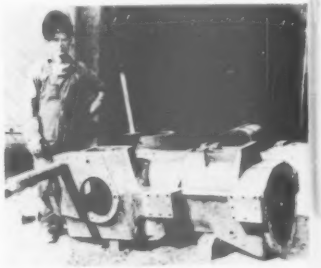
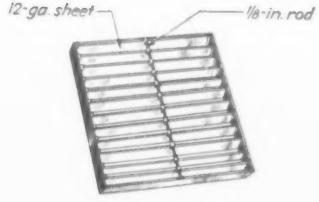


Fig. 3 Paul La Belle, welder, with completed assembly

Shop Ventilator

by F. C. Geibig



HERE is another item you can make to improve your shop. Most shops can use several ventilators of this type. Cut the louvers from 12-gage sheet steel and make the frame of heavier material. Bronze-weld the parts together and then tack-weld a length of $^1/_8$-in. rod to the center of each louver on each side of the ventilator. This makes the ventilator more rigid and stable.

F. C. Geibig is with The Linde Air Products Co., Newark, N. J.

Guards for Farm Machinery Are Easy To Make

Building and selling them can be a profitable sideline for the shop

by H. B. Gilson

UNPROTECTED moving parts are a constant source of danger on farm equipment. Guards like those shown in the photographs on this page are safety devices that can save farmers a lot of grief. When you alter or fabricate farm equipment in your shop install them as part of the job. A profitable business can be built up by visiting farms in your locality and pointing out the dangers of unprotected moving parts. This may be the sideline you need to keep the shop busy when repair jobs are scarce.

You will find that it is easy to make these machine guards with your welding and cutting blowpipe. Each guard can be tailor-made to fit the needs of each job. Use 16-gage sheet steel for the frame of the guard and cut it to the proper length with your cutting blowpipe or attachment. Then bend the 16-gage strip to the proper shape and weld the ends. You can make circles, as in Fig. 2, or irregular shapes, as in Fig. 3.

H. B. Gilson is with The Linde Air Products Co., Newark, N. J.

Fig. 1 After you cut and form the frame to the proper shape, tack weld the mesh screen to one side of the frame

Lay heavy mesh screen over the frame, as shown in Fig. 1, and make several tack welds. Trim off the over-

Fig. 2 Cut off the overhanging screen and bronze weld around the entire circumference

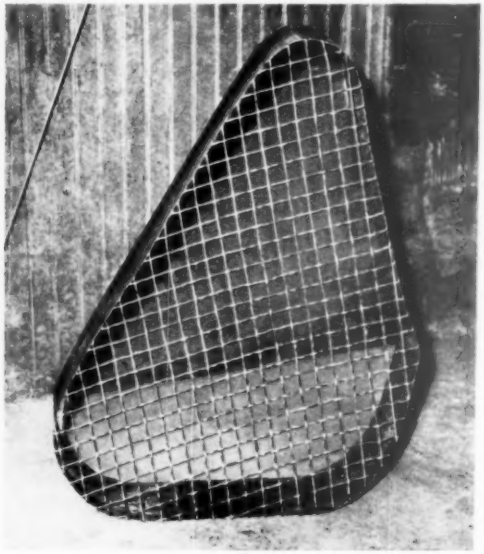


Fig. 3 A wire brushing and coat of paint produces an expert appearance. Paint the guard to match the machine

hanging screen with a pair of heavy shears. Braze weld the screen to the frame around the entire circumference. A wire brushing and a coat of paint will produce a finished appearance. Paint it to match the machine on which it will be installed. Or paint it red as a warning to the farmer that here is a danger spot.

Designing for Welding—Part IV

by Wallace A. Stanley

PROJECTION WELDING

IN THE fabrication of metal parts there is probably no single process which offers the design engineer greater opportunities to reduce costs, improve production and simplify operations than projection welding.

This form of resistance welding has so many advantages that it is surprising sometimes to find that it is not more extensively used. Among these advantages are:

1. It makes possible the assembly welding of parts with no weld marks or practically none showing on the "outside."

2. Parts can be assembled by projection welding which could not be resistance welded together otherwise. (Unusual shapes or inaccessible weld locations.)

3. Where several "spot" welds are required, it is frequently the fastest method of assembly, since several projection welds can be made simultaneously and with much less current per weld in the same material.

4. It makes for less shop maintenance, since the larger electrode contact area used for projection welding (compared with spot welding) makes for less electrode wear.

Wallace A. Stanley is Application Engineer at the Progressive Welder Co., Detroit 12, Mich.

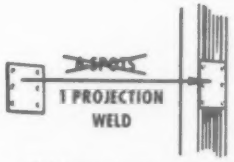


Fig. 1 Welds are formed at all dimples on each part simultaneously. (Reinforcing bracket on a bus pillar)

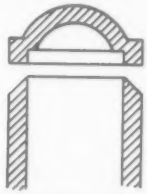


Fig. 2 A ring-type projection here provides a perfect seal of a cap on a tube without flash welding or deep drawing

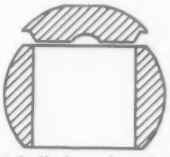


Fig. 3 A ball-shaped socket can be produced without blind drilling by projection welding a tubular part to a cap

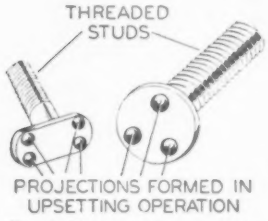


Fig. 4 These studs are projection welded to an electric iron base with no indentation or marring of the outside

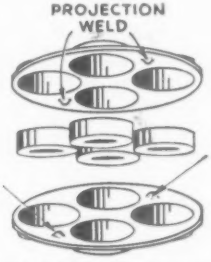


Fig. 5 Typical illustration of ingenuity in designing for a simple projection welding

Four welds are secured by putting two dimples in each stamping—making both stampings exactly alike (instead of having four dimples on one, none on the other)

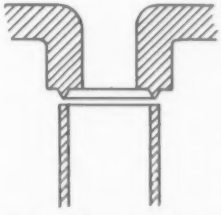


Fig. 6 Illustrating how a light tube can be projection welded to a heavier fitting by means of a simple ring projection

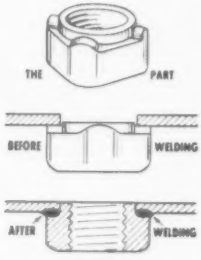


Fig. 7 Attaching a drilled and tapped nut to a large sheet metal part is made easy by 4 radial projections 90° apart

5. It simplifies the welding together of parts of different thicknesses and even of different materials.

6. Welds can be accurately located and pre-spaced on the drawing board without any variations in production.

7. Permits attaching of threaded parts with ease to larger parts which do not lend themselves readily to drilling and tapping because of their bulk. (A $\frac{1}{2}$-in. nut can be projection welded to a sheet of only 0.05 in. thickness, for example.)

8. Reduces changes of warpage in sheet material, particularly as compared with arc welding. (Eliminates most of the possible heat distortion in tacking pieces together at several points.)

These are some of the more general advantages. The extent to which each is important depends on the nature of the job and the ingenuity employed by the design engineer in adapting the job for the process.

It should be pointed out that a "projection" may take many shapes. They may be in the form of a few dimples stamped into one or both of the parts to be assembled. They may be in the shape of a "ring" or almost any other form as required by the parts. By varying the shape of the projection, the shape and character of the weld can be altered at will. In any case, however, the projection accurately determines and controls the location of the weld, since it concentrates the welding current in that exact location.

Thus, projection welding may be used to reduce cost and improve the product:

1. Instead of spot welding (Fig. 1)
2. Instead of flash welding (Fig. 2)
3. Instead of deep-drawing (Fig. 2)
4. Instead of drilling or boring (Fig. 3)
5. Instead of arc welding (Fig. 4)

(*To be continued*)

Simple Welding Process Prevents Theft of New License Tags

Newspaper reports and radio announcements warn against stolen tags. They suggest a more secure method of attachment

NEW license tags for 1949 are presenting a problem to all automobile owners who have not considered the possibility of having them stolen. Many have already found the ordinary method of bolting the 1949 tag most unsatisfactory, for it may be easily removed and stolen, with little work and practically no tools.

A leading welding electrode manufacturer has come forth with the suggestion for a more permanent method of attaching the new tags to the old plates. These tags may be easily welded with a low-heat arc-welding electrode, completely nonrusting, that will not distort, discolor or mar the plate or tag in any way. This idea will be quickly welcomed by all automobile, truck and trailer owners who have found the bolt method insecure. A small weld on each side of the license tag or along the beveled edge will make the tag burglar-proof. See photograph.

This arc-welding electrode is a low-heat electrode and is available at all automotive distributors.

Data and Photo courtesy Eutectic Welding Alloys Corp., 40 Worth St., New York N. Y.

the AMERICAN WELDING SOCIETY

activities • related events

Annual Meeting American Welding Society

The plans for the Annual Meeting of the AMERICAN WELDING SOCIETY are proceeding at a rapid rate. The meeting will be held, as in former years, in connection with the National Metal Congress and Exposition. A five-day technical program from Monday, October 17th to Friday, October 21st, has been arranged. The annual President's Reception will be held as usual on Sunday October 16th. Headquarters for the AMERICAN WELDING SOCIETY will be the Hotel Cleveland, Cleveland, Ohio. Most of the technical sessions will be held at the Hotel, except on Wednesday morning, when three simultaneous sessions will be held at the Cleveland Auditorium. The Educational Committee is planning another series of lectures at the Cleveland Auditorium on Monday, Tuesday and Wednesday afternoons, paralleling the successful series held last year.

The details of technical program of the SOCIETY has not yet been completed, but it will be announced in an early issue of *The Welding Journal*. Tentative arrangements include 21 technical sessions on almost every phase of welding, with about 70 papers carefully selected from offerings of almost twice that number.

The Convention Committee this year will be headed by Michael S. Shane, Senior Electrical Engineer, Cleveland Electric Illuminating Co., who will be ably assisted by a number of local committees of the Cleveland Section.

In order to stimulate discussion and interest in the Annual Meeting papers the same plan will be followed that was inaugurated last year of publishing as many papers as possible in advance of the meeting in the September and October issues of *The Welding Journal*. No stenotype reporter will be available, but every member of the Society who is in a position to do so is urgently requested to study these Annual Meeting papers and to submit discussion in writing preferably in advance of the meeting. There will be opportunity for oral discussion. Those having prepared written discussion will be favored in their presentation during the various sessions of the Annual Meeting.

The Adams Lecture and Prize Awards will be given on Monday Evening as heretofore. The Business Meeting and Board of Directors Meeting will, however, be held on Wednesday Afternoon. . The Annual Dinner of the SOCIETY will be held on Thursday Evening.

Recognizing the great interest in the Metal Exposition, free time has been provided for most of the members to attend either on Wednesday, Thursday or Friday Afternoon or Tuesday, Wednesday and Friday Evening.

SOCIETY headquarters has already mailed out hotel reservation notices to all members.

In view of the fact that the total hotel rooms in Cleveland are limited, every member of the Society is urged to send in his reservation as promptly as possible. The Housing Bureau will attempt to locate members whose reservations come too late to be taken care of at the Headquarters Hotel.

Western Metal Congress

Preparation for attendance of 50,000 plant operators, metal engineers, production department heads and purchasing agents has been made by the management of the Western Metal Congress and Exposition, April 11–15 in Shrine Convention Hall, Los Angeles.

The exposition will demonstrate with operating and nonoperating displays the newest developments in producing, fabricating, testing and applying ferrous and nonferrous metals. Exhibits of more than 150 nationally known firms will act as a guide for industry in choosing structural metals and metal equipment.

With the show designed solely for industry, no appeal is being made for the public to attend, says W. H. Eisenman, national secretary, American Society for Metals, in charge.

Those who belong to cooperating societies will be registered free for the full five days on exhibiting their membership cards. Tickets are being distributed by exhibitors to users and prospective users of their products.

Ten thousand from all parts of the west are expected at technical sessions programmed by the American Society for Metals, AMERICAN WELDING SOCIETY, American Institute of Mining and Metallurgical Engineers, American Foundrymen's Society and Society for Nondestructive Testing.

More than 100 authoritative speakers will deliver papers on results of recent metallurgical research, or otherwise will take part in the programs.

Cooperating societies include: American Chemical Society, American Institute of Electrical Engineers, American Petroleum Institute, American Society of Civil Engineers, American Society of Mechanical Engineers, American Society for Testing Materials, American Society of Tool Engineers, National Association of Purchasing Agents, Pacific Coast Electrical Association, Pacific Coast Gas Association, Purchasing Agents Association of Los Angeles, Society of Automotive Engineers, Western Oil and Gas Association and others.

The SOCIETY is making every effort to secure copies of the welding papers for publication in *The Welding Journal* so that they may be made available to all members.

Sustaining Member

Weltronic Co., 19500 West Eight Mile Road, Detroit 19, Mich., was organized July 25, 1938, and has its main office and factory in Detroit, Mich. The company is a leading designer and manufacturer of resistance welding controls, induction and dielectric generators, motor controls and electronic rectifiers and regulators. Their engineers and sales personnel specialize in the solving of problems and techniques related to resistance welding and electronic applications. The company has pioneered the advance of electronic resistance welding controls. Representatives for sales and service are located in major industrial areas.

Columbus Section Secretary Suffers Fatal Heart Attack

George S. Herren

George S. Herren, Secretary of the Columbus Section, suffered a heart attack while at work, on the morning of Jan. 28, 1949. Mr. Herren had been Secretary and Treasurer of the Columbus Section for eleven years and was practically the backbone of the Section.

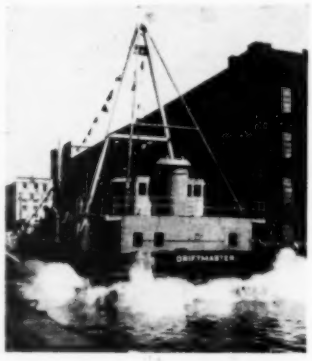
While working at Seagrave Corp., Mr. Herren met with a small group of welding foremen in 1937 and formed the Columbus Section with approximately ten members. In 1938, one or two more members were added. In the second election of officers, Mr. Herren became Secretary and Treasurer and served in that capacity until the time of his death.

It was largely through Mr. Herren's efforts that the Section thrived through its infancy and grew from ten members to its present membership of approximately 125.

NEWS OF THE INDUSTRY

Driftmaster

The appropriately named "Driftmaster" is the first scavenger boat of its kind. Built by the Wills-Spedden Shipyard, Inc., of Baltimore, Md., it is for use by the Corps of Engineers in New York Harbor to pick up or "scavenge" loose debris and driftwood floating about the harbor.



The boat has a double pontoon-like hull, is 100 ft. long, has a 36-ft. beam and grosses about 250 tons. It is Diesel powered with twin screws and twin rudders, each screw developing 350 hp. There is an engine room in each hull, pilothouse controlled. There are two chain nets for collecting debris and on deck a 12½-ton boom with an "A" frame. The boat is 100% welded.

Data and photograph courtesy, The Lincoln Electric Co., Cleveland, Ohio.

Opening of Sales Office in Seattle

Alden G. Roach, president of Consolidated Western Steel Corp., a United States Steel Subsidiary, has announced the opening of a sales office at Seattle, Wash., to serve the Pacific Northwest. The office located in the Exchange Building, Seattle, will be in charge of Hanford Haynes, active for many years in the field of steel fabrication. Mr. Haynes is a registered engineer in the states of Washington and California, and was first chairman of the Puget Sound Section of the AMERICAN WELDING SOCIETY. He has also been president of the Commercial Boiler Works, a partner in Associated Shipbuilders, and prominent in other organizations. During the war he served with the Navy in the South Pacific with the rank of commander.

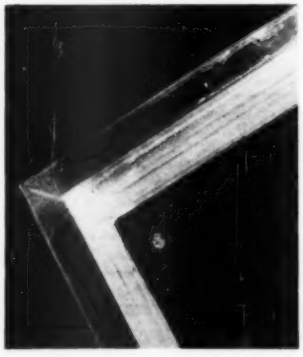
"The magnitude of the growth in population and industry in the Pacific Northwest in recent years," said Mr. Roach, "has convinced our company of the importance of direct sales contacts in Seattle, Portland, Tacoma, Spokane, Olympia and other principal cities in the Pacific Northwest. Our activities in this area are steadily increasing, and include the fabrication and installation of 5000 tons of pipe, 12 ft. in diameter, for the Grand Coulee Dam pumping station where river water will be lifted approximately 400 ft. for irrigation purposes; extension work at the Tacoma smelter of the American Smelting and Refining Co.; and the erection of steel tanks in the Hanford Works.

Joining of Thin Aluminum

The joining of thin aluminum has always presented a problem to production welders who require an alloy that will not warp or distort the aluminum surfaces. A new development of Eutectic Welding Alloys Corp., New York, called Eutecrod 900X, solves these difficulties by joining thin aluminum at temperatures below melting point of aluminum with greater fluidity than attained by aluminum brazing.

Eutecrod 900X is an aluminum alloy used with low heat Eutector Flux 900X, that supplants the common methods of aluminum brazing and fusion welding. The unusually low heat at which this alloy is applied makes it desirable for manufacture of all light gage aluminum parts, tubing, sheet, bands, shapes, without fear of distortion. Its use throughout major industries is unlimited: aircraft construction, aluminum trailer bodies, metal goods, aluminum furniture, aluminum utensils, etc.

Eutecrod 900X is available in $^{3}/_{64}$ and $^{1}/_{32}$ in. in coil form. It bonds at 900° F. and remelts at 950° F. It has a tensile strength of 30,000 psi. and is used with corresponding Eutector Flux 900X to guarantee lowest heats of application.

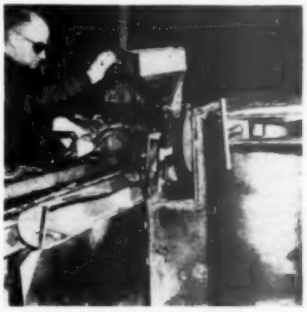


Direct contact of the heat source is not required so that all possibilities of warping or melting base metal is avoided.

Write to Eutectic Welding Alloys Corp., 40 Worth St., New York 13, N. Y., for additional information.

Spring Loaded Head Makes Curved Weld

A midwestern manufacturer uses a track-mounted Unionmelt welding machine to weld a seam on the curved front surface of a hot-air furnace. The welding head is left free to swing but a restraining spring holds the guide wheel against the curved front section, thus keeping the welding rod in alignment with the seam.



Welding rod and granulated welding composition are automatically fed to the welding zone. Welding takes place beneath a protective cover of welding composition without flash or spatter. The resultant weld is clean and uniform and requires no subsequent chipping or peening. Welding speed for this application is approximately 46 in. per minute.

The speed and uniformity of this process of welding led the manufacturer to introduce it wherever possible in his production line. Special fixtures were made so that the round top and the vertical side seams could also be welded by this process.

Maintenance Training School for Resistance Welding Users

A long-range program of training, designed to increase the use of resistance welding and to assure more productive use of spot, projection, flash, seam and gun welders, has just been announced by the Progressive Welder Co., of 3050 East Outer Drive, Detroit 34, Mich.

"We have always felt," said John D. Gordon, Vice-President & General Manager, "that the greatest limitation on the use of resistance welding has been the

"FLEETWELDERS" ELIMINATE ARC BLOW ...increase welding speed 10%

By J. K. GANNETT
Vice President in charge of Engineering and Research,
The Austin Company,
Cleveland, Ohio

J. K. Gannett

The solid, uniform welds required in our heavy structural work are now being made easier and at lower cost with AC arc welding. By eliminating the restrictions of arc blow in the construction of heavy structural weldments like the roof truss shown, our fabricating shop is today able to take full advantage of higher welding currents with resulting substantial increases in welding speeds.

Structural members like the jack truss shown in the photographs are shop fabricated from wide flange beams and from plate. Component members are first positioned accurately for close fit-up and tack welded. One side is then partially welded with fillets of ¼" "Fleetweld 7" electrode using 500-amp. Lincoln "Fleetwelder" AC arc welders.

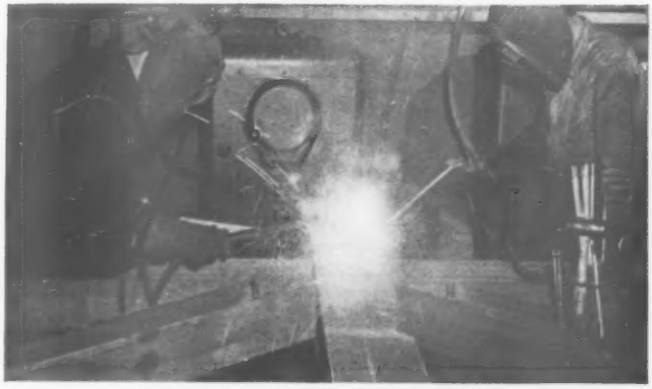


Fig. 1. *Arc welding diagonals to chord with the 500-amp. Lincoln "Fleetwelder" AC welders at the structural fabrication shop of The Austin Company.*

After the initial side welds are made, the truss is placed in an upright position as shown in Fig. 2 and continuous welds completed around each member, framing into the lower chord. The truss is then flopped over and similar welding is done for the members framing into the other chord. This procedure permits us to use fast downhand welding techniques on all connections and assures us solid, high quality welds on all joints at the lowest fabricating cost.

Using the AC "Fleetwelders," thus eliminating arc blow, allows our operators to increase their current to over 300 amperes with no difficulty in maintaining a steady, constant arc at all times. Increased amperage, combined with steady, uninterrupted operation, has cut our welding time about 10%.

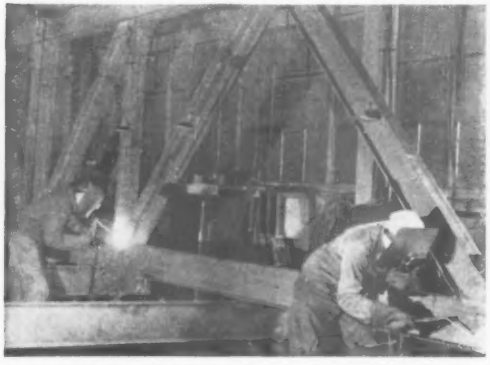


Fig. 2. *Fabricating all-welded 40-ft. jack truss for factory building framework. Top and bottom chords are 10"-21WF beams; diagonals are 8"-17WF beams. Welds are downhand, single pass, ⅜" fillets.*

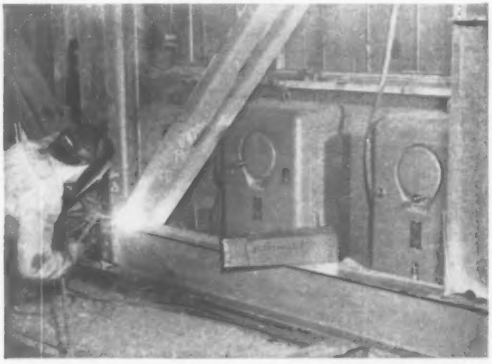
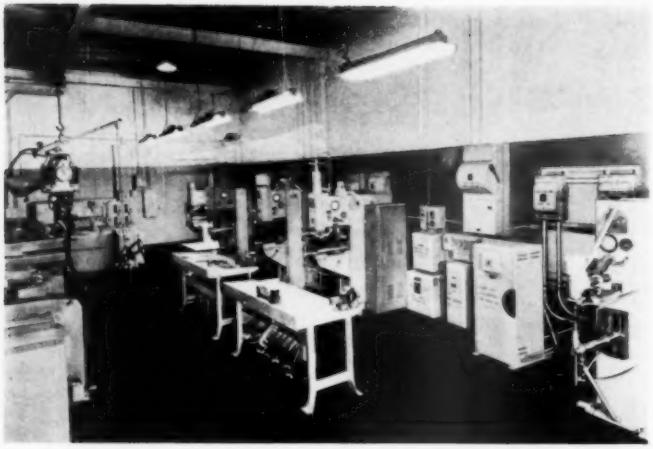


Fig. 3. *Finishing all-around welding of diagonal to bottom chord. Weld is made with single pass ¼" diameter "Fleetweld 7" electrode. Welding current is 310 amps.*

The above is published by **THE LINCOLN ELECTRIC COMPANY** *in the interests of progress.*
For further information on "Fleetwelders," write for Bul. 366. The Lincoln Electric Company, Dept. 94. Cleveland 1, Ohio.



lack of knowledge concerning its application possibilities. Unlike older and more generally known joining methods, resistance welding is largely a child of necessity born to the automotive industry only a comparatively few years ago. However, this youngster has enjoyed unusual growth due to the economic nicety with which it fits into the pattern of mass production.

"During the last war and since that time, more and more industries in every line have come to realize its potentialities. But, we believe that the real growth of our industry still lies ahead of us. For that reason, someone must provide a proper schooling in the fundamentals, i.e., how to properly maintain the resistance welding equipment now at work in industry and, secondly, how to design for resistance welding, and that is why we have opened this technical training school.

"Every resistance welding equipment user with whom we have talked," he continued, "has been enthusiastic concerning the possibilities of our school; so now we have taken the plunge we expect to carry through."

"The present course is for maintenance men only; the course on 'Design for Resistance Welding' will be started in August."

A beautiful booklet has been prepared for distribution by Progressive, outlining the plan in detail, naming faculty members and showing classroom and laboratory facilities costing more than $200,000 which have been set up for this school. No charge of any kind is made for the training course and it is open to any user of resistance welding equipment. Entry applications may be had from the Personnel Dept. of Progressive Welder Co., 3050 East Outer Drive, Detroit 34, Mich., and class assignments are now being made.

Big Dipper

The Big Dipper is in the heavens, but the biggest dipper on earth will soon be stripping overburden at an estimated rate 20% greater than heretofore in the southeastern Ohio soft coal fields. Overburden is the soil, rocks and vegetation covering veins of bituminous coal present in Pittsburgh Seam which underlies, in a northwest to southeast direction, an area from north of Pittsburgh to Charlestown, W. Va., and bulges out beneath part of eastern Ohio as well.

The biggest dipper on earth was completed last week by Lukenweld, machinery-making division of Lukens Steel Co., Coatesville, Pa., following new designs evolved by Lukens development engineers in collaboration with those of the Hanna division, Pittsburgh Consolidation Coal Co. The dipper is now en route to Ohio where it will be used in strip-mining operations near Adena, Jefferson County, a short distance from the Pennsylvania and West Virginia state lines.

The biggest dipper on earth is unique in that it is the largest ever fabricated of

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100 parts in 18 minutes..
A BONUS BY BRAZING

Furnace brazing in batches joins 100 of these aluminum parts in 18 minutes. Welding 100 parts singly takes 1 hour and 48 minutes. Other aluminum assemblies are joined 10, 12, even 50 times faster by furnace or dip brazing.

Fastening aluminum parts too thin for welding . . . think of brazing. Parts too intricate to weld . . . use brazing. Big production runs . . . the moneysaving answer is brazing. Where neat appearance counts . . . brazed joints are clean and smooth.

Brazing by molten flux bath or furnace methods eliminate localized heat that causes distortion. Brazing leaves no spattering to chip or beads to grind.

An acid dip and water rinse clean off flux, leave parts smooth and bright.

THIS ENGINEER'S HANDBOOK SHOWS HOW

A file full of technical data and Alcoa's 61 years of light-metal experience is packed into this 128-page book. Send for your free copy of "Welding and Brazing Alcoa Aluminum", or ask your Alcoa salesman for a copy. ALUMINUM COMPANY OF AMERICA, 1933 Gulf Building, Pittsburgh 19, Pennsylvania.

AIR DISPENSER ASSEMBLY

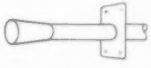
Welded: 100 parts in 20 hours.
Brazed: 100 parts in 2 hours.

FLANGED TUBE ASSEMBLY

Welded: 100 parts in 1.8 hours.
Brazed: 100 parts in 18 minutes.

OIL-TANK FILLER NECK PAN

Welded: 100 parts in 8 hours.
Brazed: 100 parts in 40 minutes.



MAGNETO BLAST TUBE ASSEMBLY

Welded: 100 parts in 12 hours.
Brazed: 100 parts in 14 minutes.

ALCOA FIRST IN ALUMINUM

ALCOA ALUMINUM

Announces

A COMPLETE NEW LINE OF A-C ARC WELDERS

Alternating current welding has proved to be the most practical and efficient method of arc welding for 75 to 80% of all welding applications—light or heavy-duty jobs . . . production or maintenance welding . . . large plant or job shop . . . mild steel or special alloy. ***And here are eight brand new General Electric welders that make a-c welding better and easier than ever.***

Capitalizing upon the advantages inherent in a-c welding (no troublesome arc blow, faster welding, low power consumption, and minimized maintenance), these new a-c welders give you 1949 "plus" value in the form of *wider welding range, greater efficiency, improved design throughout.*

They are available in 200-, 300-, 400-, and 500-amp models for indoor manual welding; the 300-, 400-, and 500-amp models are also offered in a special weatherproof housing with Idlematic control for indoor or outdoor operation. For light-duty, job-shop welding, a special 160-amp model is available; and for machine and submerged melt welding, 750- and 1000-amp a-c welders can be supplied.

Check the 8 big features for '49 offered by all these models. Then draw a bead on that little, old coupon in the lower right-hand corner and mail it to your G-E Arc-welding Distributor, or direct to the General Electric Company. For a 3¢ stamp, you can't afford to miss the rest of the story on this latest addition to the G-E line of arc-welding equipment.

8 BIG FEATURES HELP YOU MAKE THE MOST OF WELDING ABILITY

1. *Wider Current Range*—Dual current ranges on every model, plus generous overtravel, provides a range from as low as 30 amps to as much as 40% over model rating (for short periods).
2. *Built-in capacitors*—Help keep power costs low by correcting power factor; also reduces the necessary investment in power line, shop wiring, switches, etc.
3. *High efficiency*—More weld-metal deposit for power consumed means more welding dollars in your pocket.
4. *New Housings*—Provide better appearance and greater strength and protection.
5. *Stepless current control*—No series of plugs . . . no switches . . . just an easily turned hand crank that provides an infinite number of settings over the entire current range.
6. *Fingertip adjustment*—A child could readily operate the bearing-mounted current-adjustment crank.
7. *Fan-forced ventilation*—Means cooler operation, longer life and eliminates "dead weight."
8. *Optimum open-circuit voltage*—75-v on indoor models; 30-v on outdoor, provides maximum operator protection while assuring excellent welding performance with the widest selection of electrodes.

300, 400, 500-amp models are available

in special weather-proof housing with Idlematic control for welding indoors or outdoors.

GENERAL ELECTRIC

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RE-DESIGNED FROM TOP TO BOTTOM TO HELP YOU . . .

INCREASE WELDING OUTPUT

IMPROVE WELD QUALITY

REDUCE WELDING COSTS

200 amp

300 amp

500 amp

400 amp

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Mail to your G-E Arc Welding Distributor, or direct to:

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Apparatus Department
General Electric Co.
Schenectady 5, N. Y.

Those new a-c welders sound good to me; send me a copy of your bulletin GEA-5279.

Name_____

Company_____

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City_____ State_____

55 cubic yard Dipper

welded steel plate construction. The basic structure is made of manganese-molybdenum and austenitic steel plates, 1 to 3 in. thick, sheared, shaped and otherwise formed, assembled and welded. Fully 90% of the steel plates have an ultimate tensile strength of 110,000 psi.

That is necessary strength, for the bucket of the dipper, approximately 11 x 13 x 12 ft. will handle a heap load of 55 cu. yd. of earth with each scoop. Operating with its 54-ft. long "stick" which is also of fabricated steel plate, it can cut a path 80 ft. deep into the earth by 90 ft. wide, without moving from its position. The dipper is portable, however, since it is mounted on a chassis equipped with caterpillar treads. It is operated by electric power.

Nooter Boiler Officers

The board of directors of John Nooter Boiler Works Co., St. Louis fabricators of industrial tanks and vessels, has announced the re-election of Harry Nooter as its chairman and Elmer J. Nooter as company president.

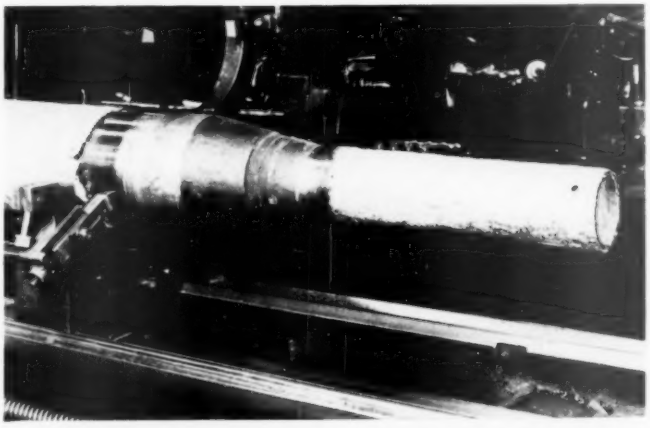
R. J. Ryan, vice-president and general manager, has taken the new title of executive vice-president. S. C. Tracy, former secretary-treasurer, has been elected vice-president and treasurer.

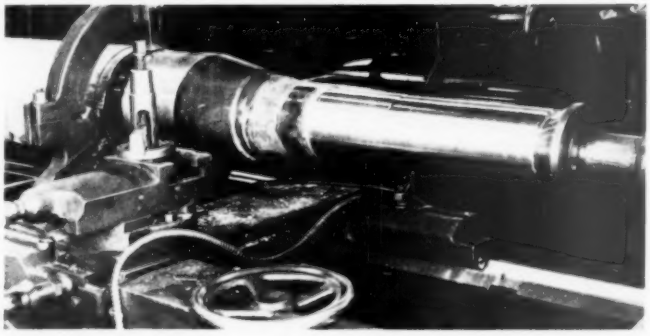
Saves Giant Glass Manufacturing Roll Through Overlay

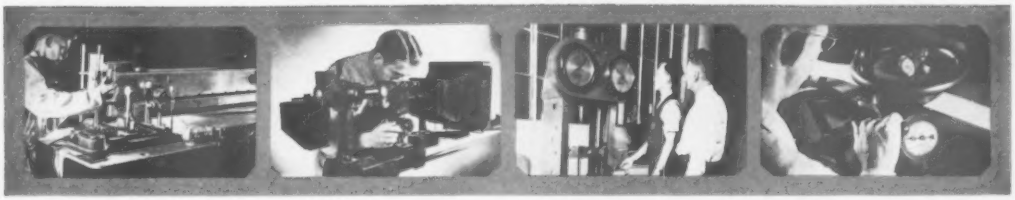
A huge precision-ground roll used in glass manufacturing was warped beyond specific dimensions as a result of the heat treatment involved. The machined ends were no longer concentric and this Glass Co., was faced with either discarding the roll on which $15,000 had already been invested, or trying to build up the warped end and machining it down to size.

The roll is 20 ft. long, made of Nichrome steel with 1020 steel welded on the ends. Corrugated wrapped section in the photographs shows the area that is precision ground and polished. This glass manufacturer built up the warped ends with Bronzochrom 185FC, a hard yet machinable alloy manufactured by Eutectic Welding Alloys Corp., New York. A slight preheat was first applied to the entire length of weld area, working around all sides to prevent overheating. The welding process was alternated from one end to the other and an air hose played on the polished roll to protect the entire section from overheating. Bronzochrom 185FC is a patented alloy, flux-coated for lowest heat applications, bonding at only 1000–1200° F. It work hardens from Brinell 180 to 235. The entire job on this roll used only 39 lb. of Bronzochrom 185FC, size $^3/_{16}$ in., and was done in the short time of 7$^1/_2$ hr., with only 6 additional hours for final machining.

Below is shown a huge glass manufacturing roll which was warped by heat treatment and saved by overlaying the end shaft with Bronzochrom welding alloy. The upper view shows the roll after welding. The lower view shows the roll machined to concentric dimension







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Investigation into every phase of low-temperature silver alloy brazing is being carried on continually in our Research Laboratories.

Believing that many engineers are interested in the valuable factual data and new findings being uncovered, we are making the data available in the form of Bulletins, two of which, covering characteristics of various types of silver brazing alloys, have already been published. Included among the subjects of future bulletins are—

- Strength of Joints—Tensile, Shear, Impact and Fatigue
- Joint design from Standpoint of Stress Distribution
- Expansion and Contraction of parts in Brazing
- Diffusion and Alloying with Joint Components
- Fluxes—Functions and Special Compositions
- Brazing Cast Iron

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New all-steel container is easy to stock—easy to see in a busy shop—and moisture-proof container keeps rods dry always!

Electrodes are packed in 5 and 10 lb. containers that hold just the number of rods that are easy for a welder to handle!

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Container

FOR ALLOY RODS CO. ELECTRODES

Simplify stock problems with superior Alloy Rods Co. electrodes in the *new* all-steel yellow and red container. Packed in 5 and 10 lb. lots so you can issue *just the right number* of electrodes from stock for true welding economy. Rods stay dry, in prime condition, because container is *moisture-proof.* Brilliant colors make this electrode container *easy to spot* in a busy shop. Order Alloy Rods Co. electrodes for better welding results . . . packed in the all-new steel container for easy handling and better stock control.

After removing rods required for job, replace top. It seals out moisture, keeps rods in prime condition.

NOW AVAILABLE ACROSS THE NATION FROM YOUR ALLOY RODS CO. DISTRIBUTOR

Write for the address of the one nearest you and for full information on *all* Alloy Rods Co. arc-welding electrodes.

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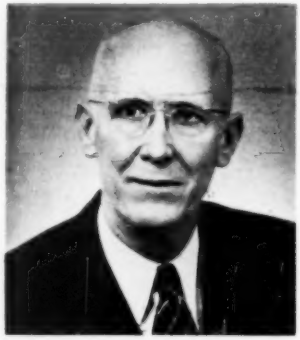
FLAMING-ARC Trademark

PERSONNEL

Owens Establishes Special Services Organization

James W. Owens has resigned from Fairbanks, Morse & Co. on January 1st to set up The James W. Owens Administrative & Technical Services at 550 E. Grand Ave., Beloit, Wis. These services will make available to industry and government a wealth of experience in standardization and the development of welding, its allied and other processes. Mr. Owens, through conference with management, will be able to assist in the development of suitable standards, welding organization, design and salvage, inspection, publicity, lectures, research and service. From 1946 to 1949



Mr. Owens was Technical Assistant to the General Manager of Fairbanks, Morse & Co.; from 1935 to 1946 he was Director of Welding at the various plants of that Company; from 1933 to 1935 he was Organizer and Director of The National Weld Testing Bureau of the Pittsburgh Testing Laboratories; from 1930 to 1933 he was Technical Director, Secretary, and member of the Board of Directors of the Welding Engineering and Research Corp.; from 1926 to 1930 he was Director of Welding at the Newport News Shipbuilding and Dry Dock Co.; from 1918 to 1926 he was Welding Aide for the Bureau of Construction and Repair of the U. S. Navy, and Assistant Shop Superintendent at the Norfolk Navy Yard.

Mr. Owens is well known to the AMERICAN WELDING SOCIETY. He was first Chairman of the A.W.S. Nomenclature, Definitions and Symbols Committee and first Chairman of the Society's Marine Committee. He was author of chapters in the first and second editions of the *Welding Handbook* and is assisting in the preparation of a chapter on Inspection in the third edition. He is author of a book on *Fundamentals of Welding*, published by the Penton Publishing Co. in 1923. He has written numerous technical papers and articles for technical and scientific magazines. He is the inventor of four patents. In 1928 he won the first prize of $10,000 of the Lincoln Electric Co.'s International Competition of Arc Welding Papers. In 1929 he received the Miller Memorial Medal of the Society.

Southern Oxygen Officers

At a meeting of the Board of Directors of the Southern Oxygen Co., Inc., held February 23, 1949, R. P. McMillan, formerly Vice-President and General Sales Manager, was appointed Vice-President and General Manager of the company. He will retain the general direction of the company's sales.

The other officers of the company are: R. B. Swope, President; W. N. Howison, Secretary; R. L. Swope, Treasurer; H. E. Eby, Assistant Treasurer.

Dr. G. V. Slottman Research Head

Dr. G. V. Slottman has been appointed director of research and engineering for Air Reduction Co., according to an announcement by John A. Hill, president.

Dr. Slottman, who joined Air Reduction in 1934, served as manager, technical sales division, and, on January 1, 1948, was appointed technical assistant to the vice-president in charge of sales, a position he held until his recent appointment.

He has been closely associated with Air Reduction's development and introduction of steel-making processes using large quantity, low-purity oxygen for both combustion purposes and as a chemical reagent. He has also written for publication a number of articles on these topics.

A native New Yorker, Dr. Slottman was graduated from Massachusetts Institute of Technology in 1925. In 1927, he received his Ph.D. from the University of Berlin and returned to M.I.T. as a professor of chemical engineering.

From 1930 until he joined Air Reduction, Dr. Slottman served as Chief Combustion Engineer and Iron Works Manager for the United Steel Companies, Ltd., Sheffield, England.

Lehigh University Metallurgist Honored

Gilbert E. Doan, Lehigh University professor since 1926, received the Stoughton award for his metallurgical work at a dinner meeting on February 4th of Lehigh Valley's American Society for Metals. Dr. Doan was credited with aiding in making "the greatest contribution to the advancement and use of welding" through utilization of the gamma ray for inspection of welds and castings.

Chapman Made Chief Metallurgist

Appointment of E. Corbin Chapman as Chief Metallurgist of Combustion Engineering-Superheater, Inc., New York, has been announced by Martens H. Isenberg, executive vice-president of the Company.

Mr. Chapman has been employed by Combustion since his graduation from Cornell University in 1928. He is the author of numerous articles and papers on welding and metallurgical subjects, of the chapter "Welding of Chromium Iron and Steel" of the *Welding Handbook* and co-author of the chapter "Relief of Residual Stresses" of the *Metals Handbook*. He is a past southern vice-president of the AMERICAN WELDING SOCIETY, has served as chairman of the A.S.M.E. Committee on Allowable Stresses for Ferrous Materials, and is a member of the following committees: A.S.M.E. Committee on High Alloy Steels; A.S.M.E. Committee on Welding; A.S.M.E. Committee on Vessels for Low Temperature Service; A.S.M.E. Committee on Clad Steels; Army Ordnance Advisory Committee of the AMERICAN WELDING SOCIETY; Pressure Vessel Research Committee of the Welding Research Council.

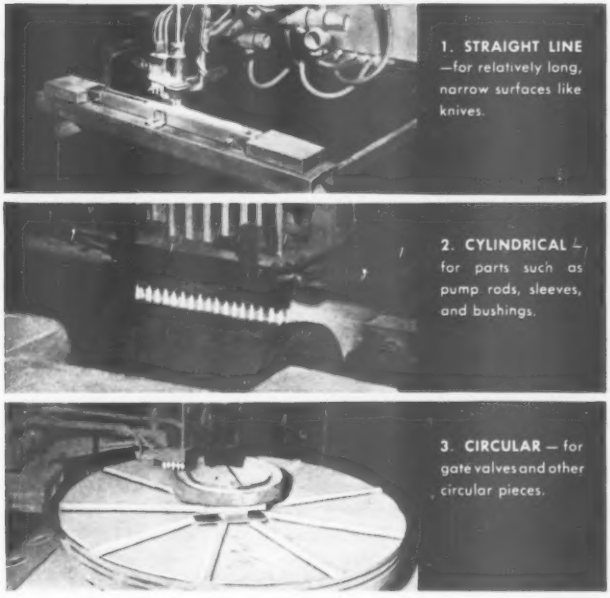
Mechanized Hard-Facing

for surfacing parts faster, more economically

Advantages over Manual Methods

- Up to 4 times faster
- Smoother, more uniform deposits
- Less rod required per piece surfaced
- Finishing time reduced

Three Mechanized Hard-Facing Methods



1. **STRAIGHT LINE** —for relatively long, narrow surfaces like knives.

2. **CYLINDRICAL** — for parts such as pump rods, sleeves, and bushings.

3. **CIRCULAR** — for gate valves and other circular pieces.

Mechanized hard-facing is a new and economical process developed by Haynes Stellite Company for applying a protective surface to wearing parts on a production basis. With a mechanized setup, parts can be surfaced up to four times faster than by manual methods. In addition, less hard-facing material is required per piece surfaced. The deposits produced are smooth and uniform, and therefore require less finishing time.

For full information on mechanized hard-facing, write to Haynes Stellite Company, Kokomo, Indiana. If you want help in determining whether any job in your shop should be mechanized, ask to have a service engineer call.

HAYNES alloys
TRADE-MARK

The registered trade-mark, "Haynes," distinguishes products of Haynes Stellite Company.

Haynes Stellite Company
Unit of Union Carbide and Carbon Corporation
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General Offices and Works, Kokomo, Indiana
Sales Offices
Chicago—Cleveland—Detroit—Houston
Los Angeles—New York—San Francisco—Tulsa

During World War II, Mr. Chapman served as supervisor of the National Defense Research Council project on development of electrodes for welding armor plate.

Mr. Chapman will continue to make his headquarters at the Company's plant in Chattanooga, Tenn.

J. K. Calhoun Joins Bastian-Blessing Co.

James K. Calhoun has joined The Bastian-Blessing Co., Chicago, as a sales engineer for RegO welding and cutting equipment, announces Ellsworth L. Mills, vice-president of the company.

A graduate of Northwestern University in industrial engineering, Mr. Calhoun had his first business experience in the engineering and sales departments of the North Shore Gas Co., Waukegan, Ill. He then went with United Cities Utilities Co. of Chicago as a field engineer and later as assistant general manager.

For two years before coming to RegO, Mr. Calhoun held the position of secretary of Metrogas, Inc., Chicago.

OBITUARY

Biographical Sketch of E. J. Rigby

In a recent issue we announced the death of E. J. Rigby, one of Melbourne's most outstanding personalities, who passed away on October 24, 1948. He was in his 90th year, having been born in Melbourne in the year 1858.

He received his early technical education under private tutors, as there were no technical schools at that time. At the time of his death Mr. Rigby was Chairman of Directors of Robert Bryce & Co. Pty. Ltd. He was a foundation member of the Victorian Institute of Engineers, the Australian Institute of Mining and Metallurgy and the Royal Automobile Club of Victoria. Mr. Rigby founded the firm of Hughes, Pye and Rigby which later became the Austral Otis Engineering Co. This firm built all the cable tram power plants, and was responsible for many other important power installations.

During the early part of the World War Mr. Rigby was closely associated with A. P. Strohmenger and the Quasi-Arc Welding Co., in England, where he saw considerable welding work on ship repair, bomb case manufacture and conversion of ships' bunkers from coal to oil carriers.

Mr. Rigby returned to Australia via America, and while in the U.S.A. he was asked, on account of his knowledge of welding, to join the "Emergency Fleet Corporation"; this consisted of a body of technical men, at a remuneration of $1.00 per year, whose duty was to investigate and initiate all means of speeding up shipbuilding. He served with this body until the end of the war.

A very interesting job that also fell to his lot in U.S.A. was with the late Henry Ford, who was organizing a plant to manufacture submarine chasers on the same production line basis as he used to build cars. These had welded hulls, and many other welded parts, and Mr. Rigby advised on the organizing of the welding and training of welders for this job. They had just got to the production stage of one a day when the war terminated.

Mr. Rigby then returned to Melbourne where he introduced the Quasi-Arc system of arc welding to Australia. Until his arrival back in Australia practically all arc welding in all parts of the world was carried out with direct current generators with usually 90–110 v. Under his supervision the a.-c. welding plant, first with 100–110 v. and resistance control, and later with 70 v. and choke coil control was developed.

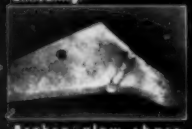
He was actively connected with welding almost up to the time of his death.

Mr. Rigby's many friends in Australia mourn his passing and pay homage to a great Australian.

(This sketch is an extract from *The Modern Engineer*, November 1948.)

A Few of the Many Applications

Plates welded with HY-LO, enameled without annealing.



Broken plow share welded with HY-LO.

Two shear blades welded with HY-LO.

Section of alloy pipe welded in three positions with HY-LO.

CHAMPION HY-LO Electrode

(HYDROGEN LOW) A.W.S.E. 7015

for Welding HARD-TO-WELD Steels

Developed primarily to enable fabricators and engineers to weld those grades of steel formerly considered unsuitable for welding, the **HY-LO Electrode** is indicated for use on sulphur free machining steel and numerous grades of low alloy and hardenable steels.

The **HY-LO Electrode** greatly increases the latitude of welding operations and permits employing welded construction in a broad field of applications.

SEND FOR DESCRIPTIVE CIRCULAR

CHAMPION'S line of HY-LO Electrodes includes E-8015, E-9015 and E-10015 for higher tensile and higher alloy steels.

You'll want a copy of our new booklet "HOW to CHOOSE and USE the CORRECT ELECTRODE." Write for it.

THE CHAMPION RIVET COMPANY

CLEVELAND, OHIO — EAST CHICAGO, IND.

YOU CAN BE **SURE**.. IF IT'S

Westinghouse

...to clear the way to big A-C Welding savings!

Now, it is no longer necessary for you to pay a premium price on a-c electrodes. The popular Westinghouse ACP electrode (equal performance on a-c or d-c), along with the complete line of Westinghouse a-c—d-c electrodes, is now available to you at the same price as straight d-c electrodes. This is of particular significance because it permits you to take full advantage of the enormous savings of a-c welding without the penalty of higher electrode costs.

Even in cases where only a few welding machines are used, the switch from d-c to a-c promises substantial savings in power, in wages and in maintenance.

Savings in power—because a-c welding requires one-third less power, giving 85% to 90% efficiency as against 55% to 65% for d-c machines.

Savings in wages—because a-c welding is 20% to 30% faster, permitting excellent welds at higher speeds on all classes of work.

Savings in maintenance—because a-c welders have no rotating parts. There are no brushes to replace . . . no commutators to clean or machine . . . no need for frequent greasing. But this is only part of the story. For the complete information on the savings opportunity this adjusted electrode price offers, send for Booklet B-4199. Address Westinghouse Electric Corporation, P. O. Box 2025, Buffalo 5, New York. J-21520

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EVERYTHING for Welding ANYTHING!

NEW LITERATURE

New Engineering Data on Selenium Rectifiers

A new comprehensive booklet on selenium rectifiers of value to electrical engineers has been published by Fansteel Metallurgical Corp., North Chicago, Ill.

Pointing out the limitations as well as the capabilities of selenium rectifiers, the book is designed to aid users of rectifiers to select, buy and use them properly.

Among the subjects discussed in text, charts and tables are: cell sizes and ratings, construction, protective coatings, forward and reverse resistance characteristics, grading of cells, efficiency, typical rectifier circuits, circuit formulas and constants, regulation, capacitance, aging, voltage doubler circuits, operation, temperature ranges, forced cooling, oil immersion, intermittent operation, high voltage rectifiers and suggestions for keeping costs down.

Copies will be supplied gratis upon request.

Resurfacing Worn Rolls

Metallizing saves money by rebuilding worn rolls. The January issue of the *Metco News* is packed full of facts, telling how you can save money on the maintenance of rolls.

The *Metco News* brings another highly profitable metallizing application to the attention of its readers. Read how paper mills, food, chemical, textile and printing plants, rubber processors, roofing and flooring materials manufacturers, paper box and can manufacturers, steel rolling mills and many other plants are using metallizing. Read how they save money with metallizing by surfacing and resurfacing a wide range of rolls and drums.

A large fat-rendering plant developed a new process requiring a large roll—48 in. diameter by 9 ft. long—that would withstand the corrosive action of fatty acids. It would have required 6300 lb. of stainless for the entire roll and eight weeks delivery time. So, they metallized the surface of a cast-iron roll with $^1/_8$ in. of stainless. This user saved 5800 lb. of stainless. The metallizing time was 24 hr. Stainless cost was under $300.

Another user, a Canadian paper mill, reports saving more than $1000 each on breast rolls—22 in. diameter by 13 ft. 7 in. long—by metallizing their worn bronze rolls with stainless steel.

Many other applications are also suggested such as armature shafts, bearing fits, crankshafts, journals and piston rods. Remember nothing eats up money faster than nonproductive machinery. Write for your copy of the *Metco News*, Vol. 4, No. 6. Metallizing Engineering Co., Inc., 38-14 30th St., Long Island City 1, N. Y.

Welding Controls

Welding Controls is a four-page bulletin describing operating features of improved automatic start-stop d.-c. welding control, incorporating latest changes in design. Interesting graphical presentation demonstrates power-saving characteristics of this equipment. Contains complete specifications and ordering information. DV Welding Controls, Oakland 11, Calif.

Bibliography on X-ray Analysis

Bibliography on X-ray Stress Analysis, with Subject Index, by Herbert R. Isenburger contains 16 pages and 240 references, and is priced at $3.00. Readers will find the subject index to be of particular value. St. John X-ray Laboratory, Califon, N. J.

Standard Metal Directory

The new edition is the eleventh of the *Standard Metal Directory*, the previous one having been published in 1946. The new volume contains 999 pages, an increase of 146 pages over the previous edition. It is bound in cloth, 6 x 9$^1/_4$ in. The old edition has been completely revised and brought up to date. The directory is divided into five sections, embracing iron and steel plants; ferrous and nonferrous metal foundaries; metal rolling mills; smelters and refiners of nonferrous metals; and a new section called "Metal Products Index" which lists geographically distributors of steel and metal products, arranged according to commodities.

The directory contains more than 10,000 detailed reports on steel mills, foundries, smelters, rolling mills and nonferrous metal plants, located in the United States and Canada. The plants are listed geographically and alphabetically. The reports give the name of the company, its capitalization, location of plants, company's officers, purchasing agent, sales manager, plant equipment, products manufactured and type of primary and secondary raw materials consumed. The directory also contains special lists of producers and distributors of pig iron, ores, ferroalloys; metal powder producers and sellers; smelters of primary and secondary nonferrous metals; storage battery manufacturers; galvanizing plants; railroad purchasing agents; aircraft manufacturers; dealers in used pipe and rails; scrap iron and scrap metal dealers, importers and exporters.

The directory is a valuable reference for the steel and metal industries and is of special value to purchasing agents and manufacturers.

The *Standard Metal Directory* is published by the Atlas Publishing Co., 425 W. 25th St., New York 1, N. Y., and sells for $15 a copy.

Oxygen Cutting

Oxygen Cutting: A Comprehensive Study of Modern Practice in Manual and Machine Cutting, by E. Seymour Semper, M.I.Mech.E., M.Inst. W. Published on Feb. 1, 1949, at 10*s*, 6*d*, (postage 5*d*) by The Louis Cassier Co. Ltd., Dorset House, Stamford St., London, S. E. 1, size D8vo (8$^1/_2$ x 5$^1/_2$ in.) 150 pages, illustrated with over 100 photographs and diagrams. Cloth bound with jacket.

The approach to the subject is mainly practical, although the theoretical side has not been neglected. The object throughout is to assist the engineer concerned with cutting and shaping material in a direct and straightforward manner.

The book contains an appendix on oxy-gas cutting by A. H. Taylor, M.B.E., B.Sc., A.M.I.Mech.E., and T. Bound, A.M.I.Gas E., A.C.G.I. Contents include—The Oxygen-Cutting Process: Types of Cutting Machines. Accuracy of Machine Cutting: Correct Operating Conditions. Construction and use of Guiding Templates for Machine Cutting. Factors Affecting Accuracy of Cutting. Thermal Effects of Cutting on Mild and Alloy Steels. Cost and Efficiency of Cutting: Multiple Cutting. Special-Purpose profiling Machines: Electronic Control of Machines. Portable Machines. Plate Edge Preparation for Welding: Manual Cutting: Cutting Thin and Very Heavy Sections. The Oxygen Lance: Cutting Cast Iron and Stainless Steel. Under-Water Cutting. De-seaming and Gouging. The Use of Various Fuel Gases. Oxy-Arc Cutting. Appendix I: Oxy-Gas Cutting. Appendix II: Tables for Reference. Bibliography: Index.

Murex Co.

Murex Limited, Rainham, Essex, England, has issued an illustrated booklet to present a brief survey of the different activities of the various Murex companies, as well as giving the uses for the metals, alloys and fine chemicals produced by Murex. A full list of the literature published by the Murex Companies forms part of the booklet.

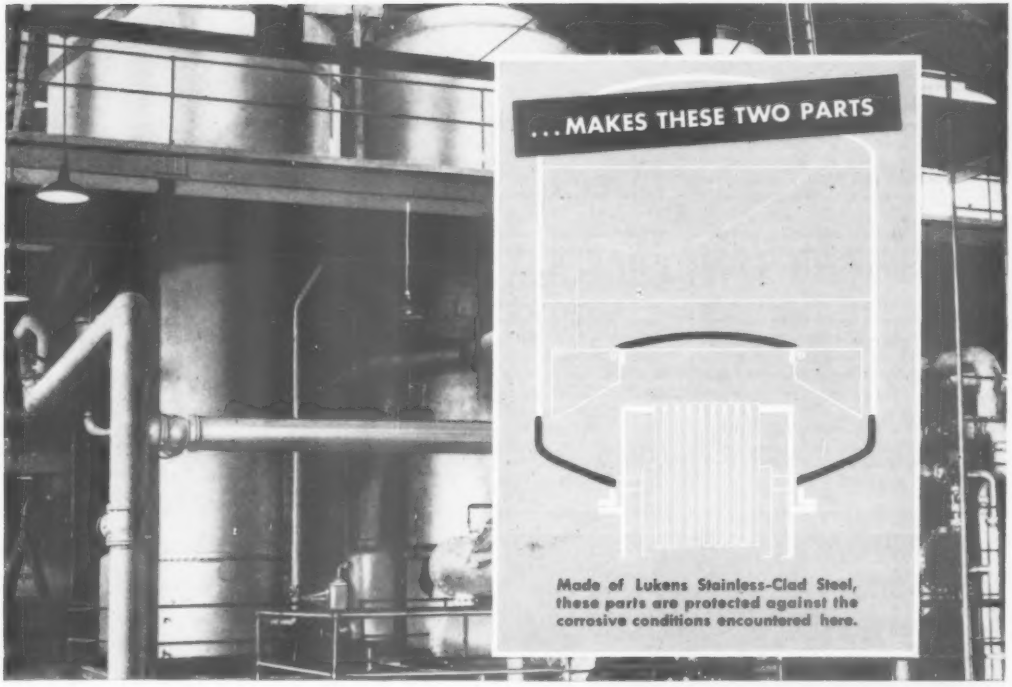
This booklet is available in French and Spanish editions, as well as the English. Copies will be sent to anyone interested.

Influence of Non-Ferrous Metals on Corrosion of Pressure Vessels

The two papers covered in this publication are: *Station Design and Material Composition as Factors in Boiler Corrosion*—R. B. Donworth, Betterment Engineer, Power Stations Dept., Duquesne Light Co.; *Corrosion of High-Pressure Steam Generators: Status of Our Knowledge of the Effect of Copper and Iron Oxide Deposits in Steam Generating Tubes*—Richard C. Corey, Supervising Engineer, Combustion Research Section, Central Experiment Station, Bureau of Mines, Pittsburgh, Pa.

Copies of this 45-page publication can be procured from A.S.T.M. Headquarters, 1916 Race St., Philadelphia 3, Pa., at $1.00 each.

ONE LUKENS HEAD-SHAPE


...MAKES THESE TWO PARTS
Made of Lukens Stainless-Clad Steel, these parts are protected against the corrosive conditions encountered here.

Starting with a Lukens Flanged and Dished Head-Shape, Swenson Evaporator Company cuts out the center and produces two parts for this vapor head—the bottom ring and the deflector. Made of Lukens Stainless-Clad Steel, both are highly resistant to the erosive and corrosive effects of the liquid which impinges against them.

Have you products with parts that are basically "head-shaped"? You can save, as other manufacturers are doing, by starting with Lukens Head-Shapes, thus avoiding those initial forming operations. Equipment and labor are released for other operations, producing more finished goods without increase in plant investment.

3,868 standard Lukens Head-Shapes are described in Lukens Catalog No. 1, enabling you to choose from them in designing new products. Many sizes and shapes in stock are listed in Bulletin No. 433. Lukens has hundreds of dies for forming others, permitting prompt shipment.

For copies of these publications, write Lukens Steel Company, 407 Lukens Bldg., Coatesville, Pa.

LUKENS HEADS

"Head Work", a 16mm motion picture in sound and color, on spinning and pressing of Lukens Heads is available without charge. Running time: 27 minutes. Write for a booking date.

FOUR INCHES TO OVER TWENTY FEET IN DIAMETER

• • SPEED SCRAP TO THE MILLS TO MAKE MORE STEEL • •

Steel Plates and Their Fabrication

Steel Plates and Their Fabrication, a reference book for engineers, and designers, who work with steel plates and with structures of which steel plates are a part, has been published by Lukens Steel Co. The 408-page book, bound in red cloth, was edited by Lionel S. Marks, Gordon McKay Professor of Mechanical Engineering, Emeritus of Harvard University.

Steel Plates and Their Fabrication contains extensive data of value for ready reference in selecting steel plates best suited to particular projects. The book contains information also on the analyses of physical properties of carbon- and low-alloy steels with charts and tables showing their behavior under sustained and repeated loadings and their resistance to abrasion, corrosion and temperatures.

The book also contains much factual material on nickel-, stainless-, inconel- and Monel-clad steels, their physical and mechanical properties and plate and head sizes.

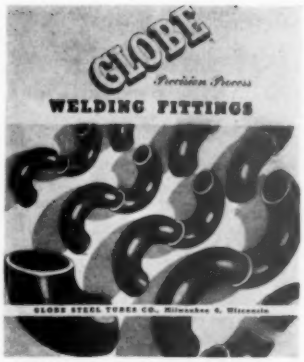
It includes historical data and information on open-hearth steelmaking, welding, the effect of plate widths on fabrication costs, strength of flat plates and shells; forming, flanging, pressing, flame-cutting; fabricated assemblies and pressure vessels and tanks. A section of more than 100 pages of general engineering information, including mathematical tables, conversion tables and other material of frequent reference, also is included.

The book is profusely illustrated with approximately 375 charts, graphs, isometric or other explanatory drawings and photographs of steelmaking and fabricating operations as well as of steel plate products and machinery.

Engineers and designers desiring a copy of the handbook should make their request on their company letterhead to Lukens Steel Co., 110 Highway Bldg., Coatsville, Pa.

Welded Bridges

The Air Reduction Sales Co. has announced the availability of a new reprint entitled "Welded Bridges." This reprint originally appeared in article form in THE WELDING JOURNAL and was written by LaMotte Grover, Airco Welding Engineer. The sixteen pages of this reprint offer a review of welded bridges constructed in the U.S.A., Canada and various foreign countries during the last twelve years and of practices in specifying steel material, details of design and methods of construction. Also included is a review of the results of some German fatigue tests of welded beams, fatigue fractures in girders and stringers of riveted railway bridges and the repairs that are made by welding. Eighteen photographs, two diagrams and four tables augment the article itself. Copies may be obtained without charge at any Airco office or from Air Reduction, 60 E. 42nd St., New York 17, N. Y.



Globe Welding Fittings

The Globe Steel Tubes Co., Milwaukee 4, Wis., has just announced a new Globe Welding Fittings Catalog. This catalog will be mailed without cost to interested engineers, executives and technical men.

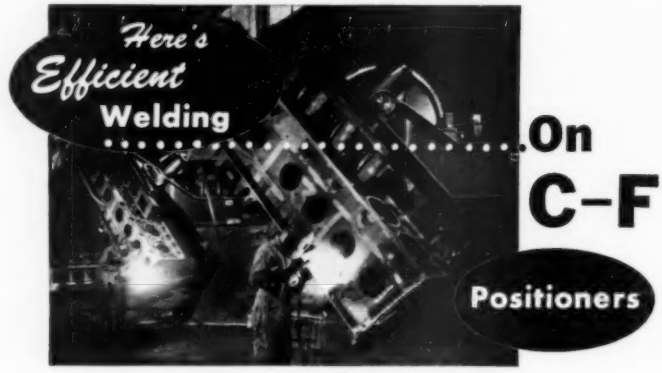
Stainless Steel

The Lincoln Electric Co., Cleveland 1, Ohio, has issued an instructive 8-page technical bulletin No. 463, describing the Lincoln stainless steel electrodes.

This bulletin covers electrodes for stainless steel surfacing and for welding the various types of stainless steels. In each instance, the information covers application, properties of deposited metal and procedure to be followed in welding.

Resistance Heater Catalog

A four-page *Resistance Heater Catalog* has just been released by the Agnew Electric Co., Milford, Mich. It describes resistance heaters that provide low-operating cost (7 to 8 lb. per kwh. at 2300° F.) and proportionately great economies for annealing and other lower temperature operations. With resistance heating the work is gripped between electrodes and low voltage, high amperage current flows through the work, its resistance causing it to heat. The low-voltage, high-amperage current used is obtained from a transformer built in the machine and connected to any standard power supply. Any work that can be gripped by electrodes and is of approximately the same cross-section area can be heated by this method. A certain section or sections can be heated and, when necessary, there can be a sharp demarcation between the heated and cool zones. These machines can be of the semiautomatic type with manual loading and unloading and automatic cycle after the work is inserted, or fully automatic machines can be furnished with automatic loading and ejection.



When heavy, unwieldy weldments like these diesel crank cases can be quickly swung into any position so that every weld is made downhand —that's efficient welding!

Weldors spend more time welding—do better welding at lower cost when they work with C-F Positioners because these hand or power operated machines reduce positioning time to a minimum. Investigate the cost-saving advantages of C-F Positioners. They pay their way in any company.

Write for Bulletin WP24—an illustrated circular detailing the specific advantages of C-F Positioners

Cullen-Friestedt Co., 1323 Kilbourn Ave., Chicago

CULLEN-FRIESTEDT CO., CHICAGO 23, ILL.

C-F positioned welds mean better, more economical welds

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Costs too high?

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For longer service at lower cost ...use Ampco-Weld repairs instead of replacement parts...

Ampco-Trode 10 Saved this Costly Cast-Iron Gear-Box from the Scrap Heap

Ampco-Trode 10 produces dense, ductile welds in cast iron with a well-brazed bond and low base-metal dilution. Ampco-Trode's ability to weld cast-iron saved the cost of an expensive replacement when this complicated cast-iron gear-box broke into two pieces. Low-cost weld repair with Ampco-Trode 10 put it back in shape for extra years of service. *(Report from Montreal Welding Co., Montreal, Canada.)*

Ampco-Trode 300 Overlays Outlast Chrome Plate 4 to 1 on Draw Punches and Rings

Draw dies fabricated and/or rebuilt with Ampco-Trode 300 last 4 times as long! This more than offsets the lower initial cost of chrome plating. In addition, press-room efficiency gains nearly 15% by eliminating down-time formerly required to hone and polish dies in the middle of production runs! *(Report from Industrial Stamping and Mfg. Co., Detroit, Mich.)*

Phos-Trode Overlays Save nearly $4000 on a Single Turbine Repair Job

More than 20 years of cavitation and pitting had nearly destroyed the vanes and buckets on these 4-ton runners of a water turbine. Replacement would have cost more than $6000 — and there was a chance the original patterns were no longer available. The unit was completely rebuilt with Phos-Trode — restored to original contour — for 1/20th the cost of a replacement unit! *(Report from Montana Power Co., Great Falls, Montana.)*

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AMPCO METAL, INC.
Milwaukee 4, Wis.
West of the Rockies it's the **Ampco Burbank Plant**
Burbank, Calif.

You can make similar savings!

Be ready to save in your plant with Ampco-welding. Keep a supply of Ampco Electrodes on hand at all times. Call your nearby Ampco Distributor for his recommendations today!

TEAR OUT THIS COUPON AND MAIL TODAY!

W-107

FREE
Money-Saving Information on AMPCO Welding Electrodes!

AMPCO METAL, INC. Dept. WJ-3, Milwaukee 4, Wisconsin
Send complete information on Ampco-Trode, Phos-Trode, and other Ampco arc-welding electrodes.

Name.....Position.....
Company.....
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City.....(.....) State.....

"WELD SECURELY"

Do YOU Specify your welding requirements this way?

Do you know what the welding requirements are for bridges, buildings, piping, storage tanks, pressure vessels or whatever your type of fabrication?

This information, necessary for solving your practical, every-day welding problems, will be found in the standards issued by the American Welding Society.

Are You

—a Designer?

—a Welding Engineer?

—a Welding Operator?

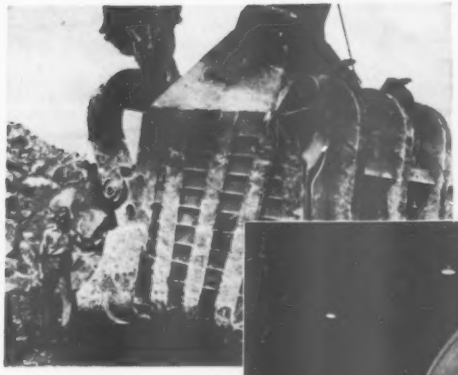
—or engaged in any other capacity as a Purchasing Agent, Salesman or Administrative Executive?

Then you should know what the material, filler metal, design, workmanship, inspection and qualification requirements are for different products and structures. You should be familiar with the standard welding nomenclature and welding symbols used in everyday welding conversation and correspondence, in technical articles and in contract specifications and regulatory requirements.

If you are not already familiar with the codes, standards and specifications of the American Welding Society as well as the educational books, ask the Technical Representative (Liaison Officer) of your Local Section for a free copy of Bulletin 101 describing these publications. Also ask about the special discounts to members. If you prefer, write directly to AWS Headquarters.

It is easy to keep informed through American Welding Society technical publications.

They will help you.
Use them!



it's ARCOS AGAIN!

IN WELDING LOW-ALLOY HIGH TENSILE STEELS

Two years ago when the Marion Power Shovel Company made this 40 cubic yard dipper, then the world's largest, Arcos engineers worked with Marion engineers to develop the welding techniques for this dipper. Today nine of these 40 cubic yard Marion dippers are in successful use in southeastern Ohio coal stripping operations.

ARCOS low alloy high tensile steel electrodes were again used to weld this 45 cubic yard dipper when Marion Steam Shovel Company along with the Hanna Coal Company undertook to make this new world's largest shovel.

ARCOS ability to provide the electrodes and to meet the problems involved in welding the low alloy high tensile steels has helped fabricators on many a difficult high tensile job.

4 ARCOS LOW HYDROGEN ELECTRODES

- ★ Require no preheat on many jobs.
- ★ Have high impact values.
- ★ Give complete range of tensile properties with high ductility.

	Yield Strength, psi	Tensile Strength, psi	Elongation in 2"	Reduction in Area
Manganend 1M	70- 85,000	90-100,000	20-30%	40-70%
Manganend 2M	85-105,000	100-125,000	10-20	15-20
Nickend 1	62- 69,000	70- 80,000	25-30	50-60
Nickend 2	65- 75,000	80- 90,000	20-30	45-60

ELECTRODES • COILED WIRE • BARE ROD •

NEW PRODUCTS

Weld-Time Meter

A new weld-time meter for measuring the duration of welding current has been developed by Westinghouse.

Four factors must be controlled in making a resistance weld properly: (1) electrode contour, (2) current delivered to the weld, (3) electrode pressure and (4) duration of welding current. The weld-time meter furnishes an accurate measure of the duration time of the weld and is used to check the schedule set by the welding control.

This unit has the following advantages:

1. It is portable and can be carried easily in one hand.
2. It is a direct reading instrument which totals the weld time and gives values in seconds and cycles.
3. It has a calibrating device built-in so that it does not need a separate source of supply, and can be built directly on to the welding machine or control.
4. It is insensitive to heat control.

Further information concerning this weld-time meter may be obtained from the Westinghouse Electric Corp., P. O. Box 868, Pittsburgh, Pa.

Spot and Arc Welders

Recently developed and placed on the market by the Delta Mfg. Div., Milwaukee, of the Rockwell Mfg. Co., are three new welders—"The Dual Weld" combination spot and arc welders, the 5-kva. spot welder and the portable 120-amp. arc welder.

Besides selling for much less than the total cost of two individual welders, the new Delta-Milwaukee Dual-Weld Combination Welder takes less than half the floor space needed by the average 5-kva. spot welder plus the average 120-amp. arc welder. It is but 14 in. wide, 19$^3/_4$ in. high and 26$^5/_8$ in. long.

Delta officials point out the fact there is no other welder like it on the market. It is especially suitable for use in maintenance and repair departments of factories, in experimental laboratories, in research departments and in radio, electric, electronic and other light metal fabrication industries. It will also find widespread use on farms, in schools, in garages, by small sheet metal contractors and in any other shop having the proper current.

The Delta-Milwaukee Dual-Weld unit spot welds, arc welds, solders and brazes. Its 10-in. throat depth permits spot welding to the center of a 20-in. sheet. A hand lever permits simple and quick changeover from arc welding to spot welding.

Especially important for nonferrous and extremely light jobs is the fact that full spot weld pressure adjustment gives infinite control from minimum to maximum pressure. Infinite adjustment and current control via the calibrated current scale is also a feature. Then too, the current scale gives accurate reading of current output, thereby allowing job records to be accurately kept for future reference on identical work. Double glass-covered wire with a wrapping of glass-mica-glass insulation and fiber-glass tape protect all transformer coils against burn-out.

New to the field of spot welders and new to the field of Delta-Milwaukee products, too, is the 5-kva. spot welder designed for manufacturing plants, light fabrication industries, sheet metal contractors and other shops and places where proper current is available.

Lower in cost than most spot welders, this new Delta-Milwaukee welder delivers a maximum of 7000 amperes and operates on 230-v., single-phase, 50/60 cycles alternating current and will weld at a production rate of 2 pieces 16-gage clean mild steel. (Not a limit but a rating.)

Operated on a reduced voltage of 115 v., the spot welder's output reduces sufficiently to make possible the welding together of extremely fine wires without overheating or burning. In addition, this new spot welder quickly and easily can be converted to a fully automatic high production spot welder by adding air equipment and a weld timer.

Another new member of the Delta-Milwaukee family is a portable arc welder, rated at 120 amp. at 25 load volts. It is a light duty limited-input transformer type welder. Operators will find myriad uses for it in farm shops, garages, repair shops, schools, maintenance and salvage departments, sheet metal shops and other workshops. It is especially suitable for the farm shop and operates on rural circuits (R.E.A.) without special consideration.

Its speedy voltage recovery provides a steady arc, and the current has infinite adjustment between 30 and 120 amp. Constructed to stand maximum abuse, the transformer is protected against grounding out or shorting. The 65-v. open circuit secondary voltage makes for unusual ease in starting arc, and the locking type jack receptacle facilitates easy removal of arc welding cable. It is mounted on removable casters and is easily portable.

Its open circuit voltage is 65 v.; its duty cycle at rated load is 20%; its current input at rated load is 33 amp. and 0.85 amp. at no load; and its power factor is 55%. The temperature rise is 90° C. Electrodes recommended for this arc welder range from $^1/_{16}$ to $^1/_8$ of an inch in diameter.

Low Hydrogen Type Electrodes

The Worthington Mower Co. of Stroudsburg, Pa., manufactures mowers for use on airfields, private estates, golf courses, parks and other large expanses of grass and foliage-covered ground.

One of the pioneers in welded design for the mower field, they were quick to see the possibilities of a recently introduced electrode, the Airco No. 394. This low hydrogen type electrode, one of the few of its type on the market, which operates on either a. c. or d. c. and gives welds up to 100,000 psi., is used by Worthington to weld high-carbon steel mower blades to mild-steel disks. The Airco No. 394 cut down rejects, due to weld cracking, by 50 to 60% with an accompanying saving in rewelding time. In addition, a higher rate of welding speed was attained which resulted in a positive increase in mower production.

fight off...

the 3 most common types of wear

√ ABRASION

The scraping type of wear... Plow shares, dredge pump blades, cinder crusher rolls and other parts that rub together or come in contact with gritty materials quickly wear out unless hard-faced.

√ IMPACT

The pounding type of wear... when metal parts smash together. Impact takes a heavy toll in shear blades, dies, punches, and hammers.

√ CORROSION

The pitting or corroding type of wear. Valve seats and disks, pump plungers, mixer blades, pellet mill plows are usually exposed to corrosion and abrasion.

with these new Hard-Facing Rods

Here are 3 new rods designed to meet the most severe conditions of wear. They are all easy to apply. Use them to hard-face the wearing parts of your machines and equipment.

"HAYNES" 90 ROD...

This rod is hard enough to resist abrasion... tough enough to stand up under impact without chipping or spalling, and will withstand temperatures as high as 1,000 deg. F. without crumbling or flaking off.

"HAYNES" 92 ROD...

The hardest of the 3 rods and the easiest to apply. HAYNES 92 has a low melting point that makes it ideal for hard-facing extra-large parts that are difficult or impossible to preheat. It is excellent, too, for hard-facing thin sections that might warp or buckle under too much heat... and it is extremely wear-resistant.

"HAYNES" 93 ROD...

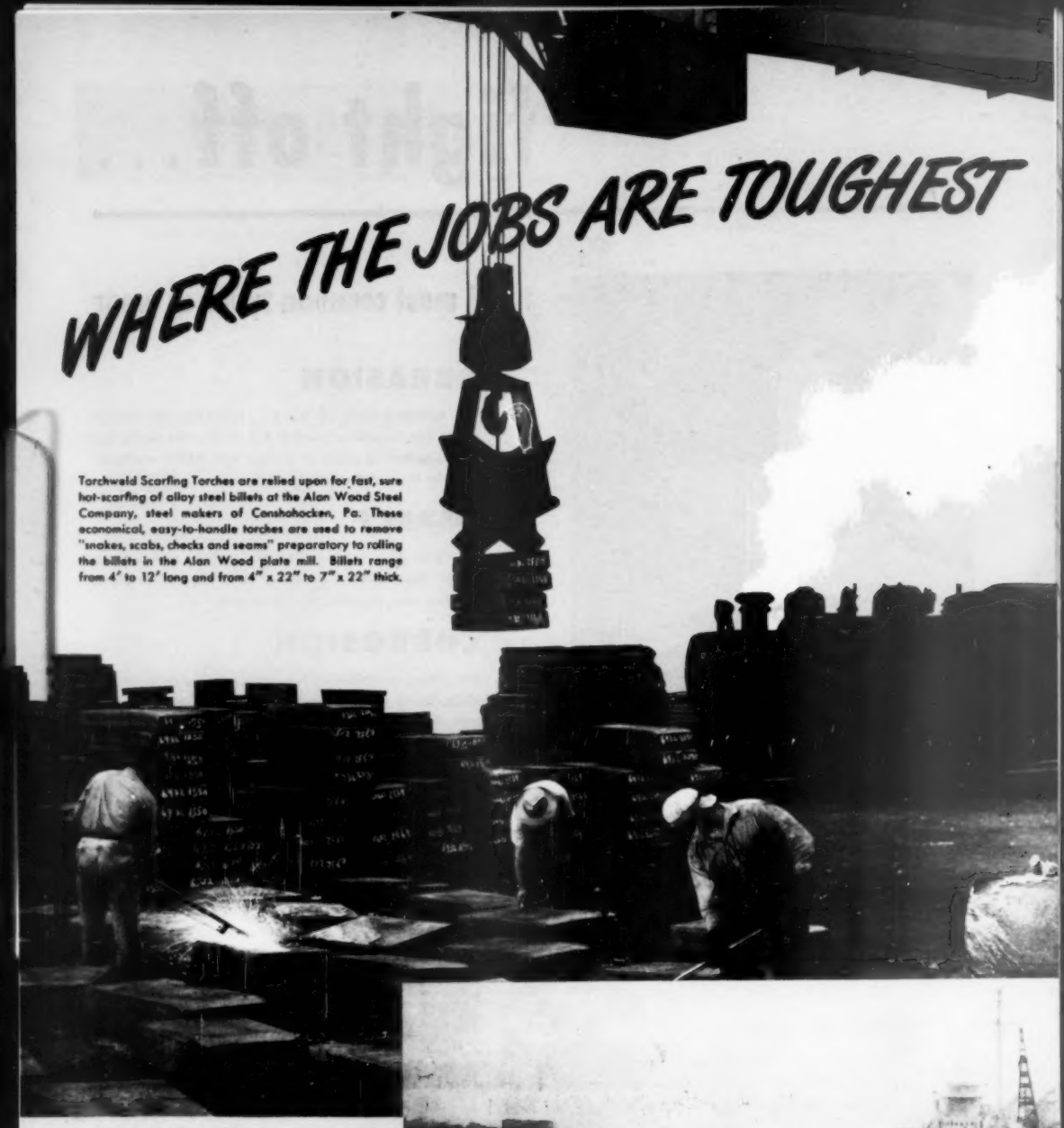
The rod with the highest alloy content of the three. More than 40% alloying ingredients make this the best of the 3 rods for resisting corrosion. It has a high cold hardness, too, and gives outstanding service when applied to parts like dredge pump impellers, slag crusher rolls, plow shares and other parts that must stand up under abrasion.

"Haynes" is a trade-mark of Haynes Stellite Company

Order from your local Jobber

Or write us for his name and address. The Linde Air Products Company, 30 East 42nd Street, New York 17, N. Y.

WHERE THE JOBS ARE TOUGHEST



Torchweld Scarfing Torches are relied upon for fast, sure hot-scarfing of alloy steel billets at the Alan Wood Steel Company, steel makers of Conshohocken, Pa. These economical, easy-to-handle torches are used to remove "snakes, scabs, checks and seams" preparatory to rolling the billets in the Alan Wood plate mill. Billets range from 4′ to 12′ long and from 4″ x 22″ to 7″ x 22″ thick.

Where speed and cost are of utmost importance, at Quaker Shipyard & Machine Co., Camden, N. J., one of the nation's largest marine scrapping operators, NCG gases are kept flowing conveniently, economically and in adequate volume, with an NCG pipeline system, fed from NCG bulk delivery. Quaker, repairers of ocean-going ships too, scrapped 15 of Uncle Sam's battle-scarred submarines, considered the toughest of all marine salvage.

TORCHWELD PERFORMANCE

builds the strongest friends...

The last operation in the manufacture of ingot molds at the Neville Island plant of the Shenango-Penn Mold Co., Pittsburgh, Pa., is the cutting off of "staples" with Torchweld oxy-acetylene hand cutting torches. These "staples" are handles for handling 6-ton molds during their manufacture, and are cut off after the molds are in railroad cars, ready to ship. NCG gases and apparatus have been used exclusively for the past 12 years at Shenango-Penn.

IN steel mills, scrap yards and heavy manufacturing plants all over the country you'll find Torchweld equipment coming through with that *extra* performance that makes Torchweld *tops* when the going is *toughest*. No wonder, then, Torchweld is also preferred for simpler, routine tasks. . . . *You, too,* will bring new efficiency and economy to *your* production and maintenance when you *rely* on Torchweld.

NCG

EVERYTHING FOR WELDING

NCG is recognized as one of the largest organizations of its kind in the world. It operates 73 manufacturing plants within the United States, offers supply and service through a vast network of hundreds of authorized NCG dealers and warehouses. For assured satisfaction in *your* welding and cutting needs . . .

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NATIONAL CYLINDER GAS COMPANY

Executive Offices:

840 N. Michigan Ave., Chicago 11, Illinois

Copr. 1949, National Cylinder Gas Co.

Heliarc Timer

For Heliarc spot welding, The Miller Electric Mfg. Co., of Appleton, Wis., has announced the new Model 264-T Welder-Timer Assembly. This unit consists of the Miller Model 271-A Pneumatic Timer with solenoid gas valve and flow meter assembled to the Miller Model 264 A.-C. Arc Welder for Heliarc Spot Welding—a complete "package" requiring only connection to input power, Argon gas, water lines and the Heliarc torch.

The arc welder features continuous current control, with adjustment to the fraction of an ampere simply by rotating the control crank on top of the machine. The Miller high-frequency unit and an extra heavy primary contactor with 110-v. operating coil are built in. The welder is provided with 220/440 v. primary connections. Power factor correction to give the unit a higher power factor and reduce the kva. demand load and primary ampere input is available as optional equipment.

For regular Miller Heliarc welders of sufficient capacity, a Miller control apparatus for Heliarc spot welding is also available. The addition of the required model, either 271-A, 271-B or 271-C, will make these welders suitable for Heliarc spot welding.

Illustrated literature covering both the Model 264-T and the pneumatic control apparatus is now available.

Hydraulic Vise

The Columbian Vise and Mfg. Co., Cleveland, announces a new oil-hydraulic vise. It is a swivel-type, foot-operated, machinist's vise with 3½-in. jaw width and 6-in. jaw opening.

Being a foot-operated vise, it offers many advantages over hand-operated vises. Both hands are always free for operator to handle and position work between the jaws of the vise. Two or more pieces to be assembled by welding or soldering or any other method are easily and quickly "lined-up" when operator has both hands free. Heavy, awkward work is more quickly and more simply handled with two hands. In fact, vise operation accidents do not generally happen when operator is placing work into the vise because he has a firm grip, knows the weight and balance of the piece. It is when the piece is removed, because the operator cannot anticipate the exact time and balance of the piece when the weight is transferred from the vise to one hand.

There are substantial savings in time, less spoilage and breakage and also a reduction in accidents, because operator can control opening and closing of vise at any position at any time.

The Columbian Hydraulic Vise is made with two simple foot control pedals—one power, the other release. Power pedal provides a slow short movement of the front jaw and only eight strokes are needed for closing from full open position. Opening and closing of vise can be controlled at any point by the operator. While hydraulic pump is made with single power pedal, the pedal operates two pistons affording a greater displacement of the

Tempilstiks°

the amazing Crayons that tell temperatures

Simply mark your workpiece with the proper Tempilstik°. When the mark melts, the specified temperature has been reached.

A convenient method of controlling working temperatures in:

- WELDING
- CASTING
- FLAME-CUTTING
- MOLDING
- TEMPERING
- DRAWING
- FORGING
- STRAIGHTENING
- HEAT-TREATING IN GENERAL

Available in these temperatures (°F)			
125	275	500	1100
138	288	550	1150
150	300	600	1200
163	313	650	1250
175	325	700	1300
188	338	750	1350
200	350	800	1400
213	363	850	1450
225	375	900	1500
238	388	950	1550
250	400	1000	1600
263	450	1050	

$2 each

Also available in pellet or liquid form

FREE — Tempil° "Basic Guide to Ferrous Metallurgy" — 16¼" by 21" plastic laminated wall chart in color. Send for sample pellets, stating temperature of interest to you.

TEMPIL° CORP., 132 WEST 22nd ST., NEW YORK 11, N. Y.

We invite inquiries from reputable distributors interested in handling Tempil° products.

X-ray inspection of welds at Western Piping & Engineering Company, San Francisco.

Rugged for sure

HERE, x-ray apparatus okays another perfect, permanently leakproof joint —on a Tube-Turn equipped section of main steam line, designed for 615-650 pounds pressure psi and a superheated temperature of 850°. Tube-Turn welding fittings make for piping which will surely absorb punishment.

Leading piping fabricators choose them because dimensional accuracy, uniform wall thickness, and true circularity assure a good weld by insuring good alignment. Leading piping users approve the choice because of the all-around freedom from maintenance established by Tube-Turn welding fittings.

Advantages of the solid, welded joint are complemented by metal structure and strength at least equal to straight pipe in the fittings proper. Their smooth inner walls and smoothly functional design permit unimpeded flow, hold down erosion and pressure loss.

Tube-Turn welding fittings do two important things for you. They facilitate welding. They last the life of the pipe.

It pays to deal with the Tube Turns distributor.

TUBE TURNS, INC.

222 E. Broadway, Dept. F, Louisville 1, Ky.

District Offices at New York, Philadelphia, Pittsburgh, Chicago, Houston, Tulsa, San Francisco, Los Angeles

Write for booklet of tables, "Allowable Working Pressures of Tube-Turn Welding Fittings."

TUBE-TURN

tt

WELDING FITTINGS AND FLANGES

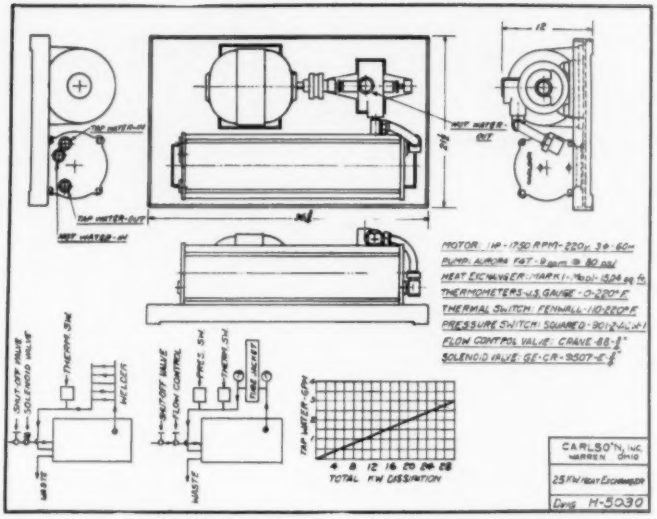
fluid which increases the closing speed of the vise jaw. The vise is opened automatically by pressure of an over-sized coil spring. The jaw is stopped at any desired position by removing pressure from the release pedal. When jaws have been closed, maximum pressure for gripping and holding can be developed with two additional strokes of the power pedal—providing a pressure of 6000 psi. The vise is protected by a safety relief valve to prevent overloading of the hydraulic system and the vise itself. Every precaution has been taken to avoid leakage.

Heat Exchanger

A new heat exchanger, originally developed to meet the need for the cooling of power tubes in induction heat and RF units, is announced by Carlso'n, Inc., Warren, Ohio. This heat exchanger is also meeting a definite need in resistance welding installations.

Claiming to save from 50 to 80% of the tap water ordinarily used in resistance welding applications, the Carlso'n Heat Exchanger, Mark I, Model I, insures high and continued efficiency in the cooling circuit by eliminating scaling and corrosion in the water passages, greatly lengthening the life of electrodes by proper cooling, and reducing maintenance and downtime to the absolute minimum.

The unique construction of the unit incorporates a closed system of finned copper tubes which provide a heat transfer area of 15.04 sq. ft. for each 24 in. of tube length. Distilled water is circulated in the closed system by a centrifugal pump driven by a 1-hp. motor which has a capacity of 12.5 gal. per minute at 30 psi., and 9 gal. per minute at 80 psi. The outer shell provides a reserve of 5 gal. of distilled water, constantly circulated.

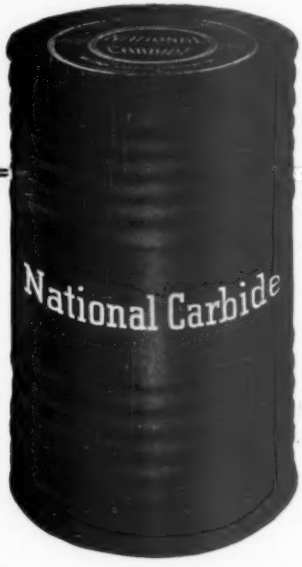

MOTOR: 1HP-1750 RPM-220v 3Φ-60~
PUMP: AURORA FGT-9 gpm @ 80 psi
THERMOMETERS: 4.5 GAUGE - 0-220° F
THERMAL SWITCH: FENWALL-110-220° F
PRESSURE SWITCH: SQUARE D-9012-G4-J-1
FLOW CONTROL VALVE: CRANE 88-3"
SOLENOID VALVE: GE-CR-9507-E-3/4"
CARLSO'N, INC. WARREN OHIO
25 KW HEAT EXCHANGER
Dwg. H-5030

Using only 0.1 gal. of tap water per minute per kw., this unit will dissipate heat to the value of 25 kw. In welding applications, a thermal switch, located at the hottest point in the cooling system, controls the tap water flow by means of a solenoid valve.

The construction of the unit permits varying its capacity by lengthening or shortening the exchanger unit, and varying the pump and motor to suit. Thus

National
Carbide
IN THE RED DRUM

EFFICIENT
ECONOMICAL
DEPENDABLE



FOR WELDING and CUTTING
Use National Carbide in the Red Drum
Write us for information as to nearest available stock.
60 E. 42nd St. NATIONAL CARBIDE CORPORATION New York 17, N. Y.

units from 12 to 40 kw. are readily available.

Entirely mounted on a cast base, with provision for drainage, and completely housed if desired, the unit's over-all dimensions are: width 36¾ in., depth 21½ in. and height 12 in.

Further information may be obtained by writing to L. R. O'Neill, Vice-President, Carlso'n, Inc., P. O. Box 846, Warren, Ohio.

Gas Torch

The new I.C.C. approved Torchmaster is a general utility, self-contained hand torch only 2¼ by 13 in. burning liquid petroleum gas (butane, propane, etc). It holds enough fuel for an average day's burning. The torch will do light brazing soldering and innumerable heating operations. It burns upside down or at any angle and has a filtered "Wind-Pruf" burner that will not clog or blow out. It is of steel construction, satin-chrome finished and of precision manufacture throughout. A single control valve turns the torch on and off and adjusts the flame from a pencil point to a roaring blowtorch. It is easy to handle, invaluable in cramped quarters and can be carried or stored anywhere. Amazingly economical, it can be filled from standard containers for from three to five cents.

Plumbers, electricians, jewelers, dentists, hobbyists, radio, refrigeration and garagemen, metal and glass workers, all find new conveniences afforded them by use of the Torchmaster. I.E.P.C. lists the Torchmaster at $19.50 without filling adapter, and offers a deluxe version, complete with adapter and iridescent baked enamel finish, for $22.50. Descriptive literature will be mailed upon request, by Industrial Engineered Products Co., 7416 Melrose Ave., Los Angeles 46, Calif.

Electrode for Cast-Iron Heavy Castings

The need for larger size diameter electrodes to handle heavy cast-iron castings is solved with the announcement by Eutectic Welding Alloys Corp., New York, of Eutectrode 24/49 in size ⅛ in.

This new rod with special Frigidare coating is particularly adaptable for overlaying and repairing large turbines, pumps, impellers, mixers, cylinder heads, housings and other heavy types of castings requiring a heavier, more substantial electrode. Eutectrode 24/49 is also available in sizes 3/16, 5/32, ⅛ and 3/32 in. for all types of cold cast-iron welding, requiring no preheating or dismantling of equipment. It avoids any of the common dangers of overheating, distortion and warping of base metal. For use with either A.-C. or D.-C. machines, Eutectrode 24/49 has a uniform burn-off rate, flows out rapidly and produces welds with tensile strength of 50,000 psi. and Brinell 150–200.

Additional information and literature may be obtained by writing to Eutectic Welding Alloys Corp., 40 Worth St., New York 13, N. Y.

Micro Hardness Tester

A new tester for micro hardness testing has just been announced by Kent Cliff Laboratories of Peekskill, N. Y. The Kentron Micro Hardness Tester is the first tester to apply accurately dead weight loads as light as 1 gm., for use with either the Knoop Indenter or the Vickers Type Indenter.

The accurate application of this 1-gm. dead weight load opens new avenues in the micro hardness testing of minute particles, inclusions, constituents, thin metals, transition zones of welds, wire, foil, ceramics, glass, enamels, plastics and jewels, both natural and synthetic.

To prepare aluminum sheet for welding

1. Use Oakite Composition No. 61 or Oakite Aviation Cleaner to remove cutting oils, forming compounds and other soils.
2. Use Oakite Compound No. 34 or Oakite Compound No. 84-A to remove oxides and smuts.
3. Look for perfect results. That's what all Oakite customers expect. That's what they get.

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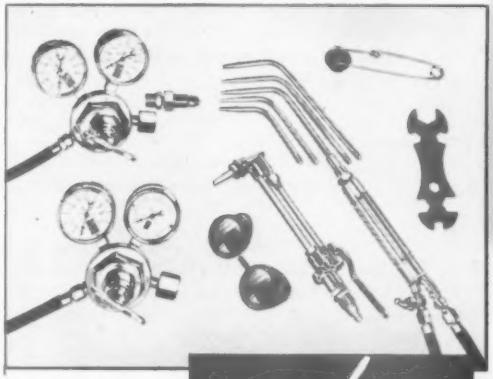

Dockson's No. 145 welding outfit shown above.

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WHY three-

The new General Electric three-phase frequency changer welding control has definite advantages for many users of resistance welders. Below are some of the questions we are frequently asked about it.

Q. I'm planning to install more machines, and my distribution lines are heavily loaded. Should I consider three-phase control?

A. Yes, because it has low kva demand, plus many other advantages. However, it may be more economical to solve your power supply problem another way —we'll be glad to help you.

Q. Can three-phase control be used for different types of welding?

A. It is used for spot, seam, projection, and gun welders, although we do not generally recommend it for the latter because it is usually economically unjustified.

Q. Where is it particularly useful?

A. In welding aluminum. There is little tip pick up and consequently not much electrode cleaning required with three-phase control.

Q. What is the difference between this system and the conventional single-phase system?

A. Basically, the method of producing a weld is the same in both. However, by converting three-phase to single-phase, low-frequency power, there is less reactance and lower kva demand. The bulletin gives more details. Now let's check the advantages shown at right.

Have you seen

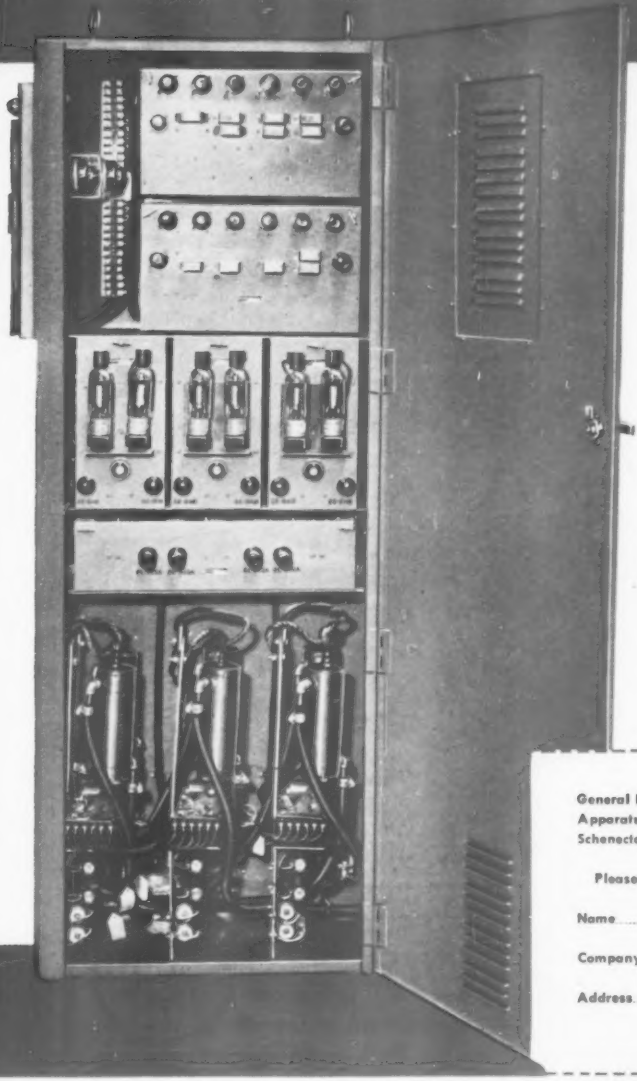
"This Is Resistance Welding"

General Electric's MORE POWER TO AMERICA full-color movie? Clearly describes and explains various types of welding—contains tips for improving production with this process. Ask your welding distributor or the nearest G-E office for a showing.

GENERAL ELECTRIC

phase control

for resistance welders?



ADVANTAGES OF G-E THREE-PHASE WELDING CONTROL

1. high power factor
2. three-phase, essentially balanced load
3. low kva demand
4. only one, compact cabinet, machine mounted
5. special features for easy servicing
6. electronic heat control
7. electronic weld timing—dial setting
8. for seam, spot, or projection welders

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Schenectady 5, New York

Please send me a copy of GEC-491 on three-phase welding control.

Name .....

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The Kentron Tester is a bench-type instrument and is hand-operated to eliminate instrument-operating vibration. An adjustable oil dash pot, for controlling the speed of load application and time of load retention, is easily adjusted to suit specific testing requirements. A specially built mechanical stage, consisting of three basic parts—the stationary plate, transfer plate and specimen block—provides an easy and convenient means for positively locating and positioning the exact area of the test specimen underneath the indenter and microscope. The microscope is mounted so it can be operated conveniently. The Kentron is stably constructed and sets on a wide spider with three-point support for ease of leveling.

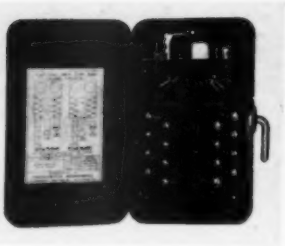
Dead weights for applying loads of 1 to 1000 gm. and the most up-to-date optical measuring equipment are supplied as standard equipment.

Kent Cliff Laboratories is licensed by the United States Government to manufacture and sell Knoop Indenters.

Timer

Photoswitch Electronic Timer, Type 30HL1, represents an outstanding advance in the field of industrial timing control. For the first time, it makes available to industry timing control with unprecedented flexibility, extreme accuracy and long-life dependability.

Type 30HL1 is an automatic timer for intervals from $^1/_{20}$ sec. to 4 min. It is recommended over all other timers—electronic, synchronous motor or mechanical—for process control and machine timing when long life repeat-cycle operation or precise accuracy is a prerequisite. This timer is used to control such equipment as spot welders, grinders, honing machines, drilling machines, conveyors, automatic filling machines and photographic printers.



Type 30HL1 provides four basic types of timing: interval, delayed action, automatic repeat and programming, as well as many variations of these four fundamental types. All of these timing combinations are incorporated in this one timer and may be utilized by merely changing external connections to the terminal board. Thus Type 30HL1 is a universal timer.

Stainless Steel Electrode

The Alloy Rods Co., of York, Pa., has just announced their new Arcaloy a.c.-d.c. stainless welding electrode which embodies a number of improvements over the conventional a.c.-d.c. electrodes currently on the market.

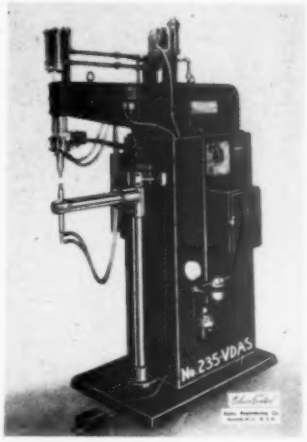
It is claimed for the new Arcaloy a.c-d.c. electrode that it has excellent arc starting qualities on all types of a.-c. welding equipment and outstanding welding characteristics on either a.c. or d.c. It has a smooth, stable arc with fine-spray weld metal transfer. The slag is easily and completely removed leaving no secondary film. The bead is uniform and full throated with straight-line feathered edges. Because of these features less cleaning, grinding and polishing time is required.

This new Arcaloy a.c.-d.c. electrode is available in all chrome-nickel analyses. Packing will be in all-steel, moistureproof containers. Folders available upon request.

Spot Welder

An improved press-type spot welder operated by a double acting air cylinder, carefully engineered for dependable high-speed production, has just been put on the market by the Eisler Engineering Co., Inc., Newark, N. J.

A prominent feature of this welding machine, shown in the accompanying illustration, is the new Solenoid-actuated 4-way air valve, which controls the air supply to both sides of the air cylinder. This valve is not only simpler in its design and trouble-free in its action, but works practically noiselessly, making it highly superior to the bulky and noisy constructions having been used before.



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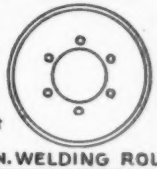

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Employment Service Bulletin

Services Available

A-570. Technical University graduate. In leading welding business position with thorough knowledge of the European welding market desires position in the United States. Preferably in the export business. Knowledge of English, French, German and the Scandinavian languages. 40 years of age.

A-571. Registered Metallurgical Engineer. M.S. Specialist in physical metallurgy of weldments involving stainless, dissimilar and low-alloy steels. Nine years' experience—six years in supervisory capacity; four years in trouble shooting, customer contacts, publications, lectures. Desires responsible position in Midwest.

A-572. Welding Engineer desires position. 37. Married. Ph.D. in Metallurgy and Welding. Graduate Mechanical Engineer. Author of numerous articles on stainless steel cutting, arc welding patents, inspection, structural welding, testing of welds. Able to read German and French.

A-573. Instructor, Inspector and Welder. Have been in the welding trade for the past twelve years, holding positions of instructor, naval inspector, assistant foreman, gang boss, technician, gas and electric welder. Have worked in shops and field construction in various states and also abroad. Will accept any type position, anywhere in the United States.

A-574. Metallurgist desires position. Age 28. Single. Graduate Brooklyn Polytechnic Institute with degree in Chemistry and Metallurgy. Two years with New York Testing Laboratory as Metallurgist. Four years with New York Naval Shipyards as Assistant Metallurgist. Have made Metallographic analysis on all types of materials, weldments, castings, production control. Made physical tests, hardness determination. Skilled in radiographic examination, foundry and welding control.

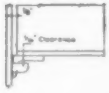
A-575. Metallurgical and Welding Engineer. Age 26. Married. Graduate Engineer. Experience in welding electrode manufacturing; also diversified metallurgical and welding experience with prominent manufacturing concern which includes welding and brazing quality control; supervision of heat treating, operation of metallurgical, physical testing, X-ray and chemical laboratory. Quality control and inspection of incoming raw material (bar, sheet, plate, forgings, and castings, ferrous and non-ferrous). Control of cleaning, finishing, and plating. Stress analysis and development work. Specification and report writing. Capable of assuming administrative position in production, engineering, or purchasing department. Prefer West coast.

A-576. Veteran, Age 37. B.S. in E.E. Thoroughly experienced in Welding, Testing, Inspecting, and Supervision in the shipbuilding trade and in machinery manufacture. Well versed in the theory and the codes and their application, and am quite able to work closely with both shop and engineering departments. Interested in both quantity and quality welding. Would consider teaching.

Positions Vacant

V-234. Wanted: Engineer for process control work in the manufacture of heavily coated metallic arc welding electrodes. Man with experience in electrode development, design and operation of manufacturing equipment preferred.

V-235. Experienced Welding Equipment Salesman Wanted to cover territory in Chicago for prominent midwestern Distributor arc welding and resistance welding machines and supplies. Excellent remuneration opportunity available. Interested only in experienced salesman with proven background in welding equipment sales. Give full particulars on education and selling experience. All replies treated as confidential.



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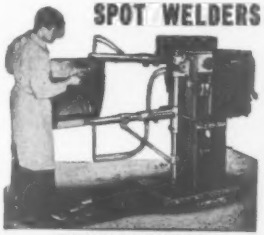

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abstracts of
CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 10, D. C.

2,459,795—Method and Apparatus for Electric Welding—John W. Dawson, West Newton, Mass., assignor to Raytheon Mfg. Co., Newton, Mass., a corporation of Delaware.

This welding method patented by Dawson relates to a process of welding two parts together which have rough surfaces in the areas at which the weld is to be effected. The method comprises bringing the surfaces of the parts into contact between the projecting high points thereof and passing a unidirectional impulse of welding current through the parts with sufficient amperage to flash off the high points and project the material forming same outwardly through the gap between the other portions of the pieces to be welded together. Then the gap between the workpieces is closed and an alternating current is passed through such parts for welding action.

2,459,796—Welding System—John. W. Dawson, West Newton, Mass., assignor to Raytheon Mfg. Co., Newton, Mass., a corporation of Delaware.

Dawson's second patent relates to a welding system wherein pressure is applied to workpieces by the electrode. An electromagnet is provided associated with one electrode for applying an additional pressure to the work, which magnet receives a voltage impulse in response to an impulse of welding current. The electrode has a high inductance to delay the rise of current therein for retarding application of pressure by the electromagnet.

2,459,812 — Welding Apparatus — Thomas W. Griffiths, Newark, N. J., assignor to Federal Telephone & Radio Corp., New York, N. Y., a corporation of Delaware.

A welding apparatus for performing a welding operation in an atmosphere of inflammable gas is covered in the patent. A container is provided for receiving the workpiece and it has an opening at the lower end thereof for escape of gas therefrom. A porous shield is positioned in the container between the workpiece and the bottom opening to prevent pieces of metal from falling through such opening.

2,459,847—Electric Flash Percussive Welding—Percy L. Spencer, West Newton, Mass., assignor to Raytheon Mfg. Co., Newton, Mass., a corporation of Delaware.

In this welding method, two metallic parts are moved towards each other until one part impinges on the other and a voltage is impressed upon the different parts to provide an arc between the parts when they are a short distance apart. A unidirectional magnetic field is set up across the space between the parts with the lines of force of the magnetic field moving directly transversely to the lines of electrostatic force extending between the parts, so that the arc is provided at a shorter distance between the parts than if the magnetic field were absent

2,459,863—Method of Electrical Brazing of Conductors—George E. Berggren, Baltimore, Md., assignor to Western Electric Co., Inc., New York, N. Y., a corporation of New York.

This brazing method specifically relates to securing two stranded electrical conductors together. In the brazing method a preformed disk of brazing material of diameter greater than the conductor is pressed against the end of one conductor and a second conductor is held against the opposite side of the brazing disk. A special electrode shape is provided so that a brazed joint can be provided of the same diameter as that of the stranded conductors secured together thereby.

2,459,957—Welding Stud—Walter E. Palmer, Fair Lawn, N. J., assignor to National Cylinder Gas Co., Chicago, Ill., a corporation of Delaware.

Palmer's patent relates to an article used in welding a stud to a plate and it includes an annular ferrule of fire resistant material which is adapted to receive the stud. A sleeve retaining fluxing composition adhering thereto is carried by the inner surface of the ferrule.

2,460,413—Welder's Double Mitt—Sanford J. Errett, Portland, Ore.

This welder's mitt is made from an outer shell which has a smooth seamless surface over the back and palm thereof and which receives a liner therein. The liner is formed from a pair of identical blanks fastened together by a marginal seam to make the liner usable with either a right or a left hand outer shell.

2,460,537—Coated Weld Rod—Ernest Clarence Rollason, Essex, England, assignor to Metal & Thermit Corp., New York, N. Y., a corporation of New Jersey.

The welding electrode of this patent has a flux coating made from an alkaline metal compound and a manganese-aluminum alloy. The alloy is made of from 50 to 90 parts manganese, 1 to 10 parts aluminum, copper and silicon not over 5 parts and carbon not over 1.5 parts.

2,460,759—Electric Resistance Welder—George B. Martin, Detroit, Mich. and Barron D. Berger, Warren, Ohio, assignors to the Federal Machine & Welder Co., Warren, Ohio.

In this patent a resistance welder apparatus is covered and it includes electrode carrying means which are movable toward or away from a work surface. A leaf spring is associated with the means for positioning the electrode and is deflectable an amount proportionate to the thrust applied. The welding operation is controlled dependent upon the deflection of the leaf spring support used.

2,460,807 — Welding Apparatus — Harry Chanowitz, Chicago, Ill., assignor to David T. Siegel, Wheaton, Ill.

A special type of a welding apparatus is covered in this patent for welding a wire that is carried by a rotatably supported mandrel. The wire is being formed into a coil on the mandrel, and an electrode is provided for shifting axially of the mandrel as well as transversely toward same.

2,460,889—Ejector Type Welding Electrode Holder—Earl I. Larsen, Indianapolis, Ind., a corporation of Delaware.

The electrode holder of this patent includes means for circulating a cooling fluid around a welding electrode and it also has an ejector piston provided in the holder. The fluid circulating means of the holder are closed when an electrode is being ejected.

2,460,988—Welding Flux—Kenneth H. Koopman, Kenmore, N. Y., assignor to Union Carbide & Carbon Corp., a corporation of New York.

The present patent relates to the welding of ferrous alloys containing substantial quantities of chromium. The welding action is conducted under a molten flux primarily comprising silica but containing quantities of borax glass, titanium dioxide, calcium oxide and sodium carbonate.

2,460,990—Automatic Electric Fusion Welding Apparatus and Process—John A. Kratz, Yonkers, N. Y., and Henry G. Thomas, Rutherford, N. J., assignors to the Linde Air Products Co., a corporation of Ohio.

This patent relates to a submerged-melt

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Revere Welding Rods are among the many copper and copper alloy products made by Revere Copper and Brass Incorporated. As with other Revere products, constant research, modern production equipment, and rigid quality control have made Revere Welding Rods unsurpassed in quality and performance.

Revere Welding Rods include: Revere 456 Low-Fuming Bronze Welding Rod, Revere Bronze 380, Manganese Bronze, Herculoy, Phosphor Bronzes, Brass (Brazing Rod), Silicon Deoxidized Copper and Electrolytic Copper. All come in 100-pound cases or in 25-pound cartons, net weight, and are stocked by Revere Welding Rod Distributors in all parts of the country.

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electric plug welding process. A welding rod is fed at a relatively slow rate into a mass of nonconductive granular materials toward a plug weld site on the work and a high-frequency starting potential is applied between the rod and the work to start the welding action. The rod feeding rate is automatically increased and the generation of the high frequency starting current is terminated as soon as the welding potential drops when weld action starts.

2,461,180—Coated Weld Rod—Ernest Clarence Rollason, Waltham Abbey, England, assignor to Metal & Thermit Corp., New York, N. Y., a corporation of New Jersey.

The weld rod of this patent to Rollason covers the same composition as that of patent 2,460,537 except that between 0.5 to 7 parts of chromium are used in place of the aluminum of the other patent.

2,461,687—Welder's Clamp—Fred P. Hopfeld, Elmwood Park, Ill., assignor to Grand Specialties Co., Chicago, Ill., a corporation of Illinois.

A special type of a welder's clamp for operatively holding and grounding a workpiece during an electric welding operation is covered in this patent.

2,461,798—Automatic Arc Starter—Nelson E. Anderson, Scotch Plains, N. J., assignor to Air Reduction Co., New York, N. Y., a corporation of New York.

This patent relates to an arc-welding apparatus wherein a movable electrode holder is provided and energizable arc-starting means for moving the holder away from the workpiece is also present in the apparatus. The arc starting means have an independent source of energy and means that are responsive to a change of voltage between the electrode and workpiece connect the independent energization source to the arc-starting means.

LIST OF NEW MEMBERS

February 1, 1949 to February 28, 1949

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Connelly, J. P. (B)
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Moore, Carl Lester (B)
Stewart, H. E. (B)

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Clouet, Herbert A. (C)

CHATTANOOGA

Pohl, LaVerne, F. (C)

CHICAGO

Arnett, Lewis V. (C)
Bacon, Harold W. (B)
Downing, H. M. (C)
Feld, Paul G. (B)
Gilbertson, Elmer G. (C)
Iversen, Ernest A. (C)
Nychay, Matt (C)
Warner, Walfrid (C)

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Fischer, J. Alfred (B)
Hanna, William K. (C)

CLEVELAND

Foster, Ralph N. (C)
Kibby, William Judson, Jr. (C)
Koenitzer, R. D. (B)
Moore, Thomas (B)
Myatt, Aloiz A. (C)
Welsch, Albert G. (D)

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Gragg, Barney M. (C)
Pittenger, Paul J. (D)
Rishell, Robert H. (C)
Shane, James H. (D)
Untereiner, Floyd V. (C)

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Huston, Clarence (B)
Oglesbee, Albert R. (B)

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Baker, Thomas R. (C)
Barkell, Wayne R. (C)
Barley, Robert (C)
Brow, Lawrence A. (C)
Collom, Cletus J. (A)
DaRonch, Mario (C)
Delazzer, McKinley W. (B)
Gibbs, Jack S. (C)
Glodowski, Thomas Z. (C)
Graham, Harold J. (B)
Greenwald, Clarence (C)
Knapp, L. J. (A)
Owocki, Casimir F. (C)
Penman, Paul J. (B)
Schroder, C. R. (B)
Volkart, Otto (C)
Wright, Leigh T. (B)
Zimmerman, Paton MacGilvary (C)

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Galanbos, Paul U. (B)

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Helmuth, Ammon (B)
Silvey, Morris A. (C)

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Sadowski, Leonard J. (B)

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Planting, Charles O. (C)

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Wellington, W. G. (C)
Zima, Albert G. (B)

LOUISVILLE

Hedrick, Paul (B)

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Bryant, Frederick E. (B)
Crutchley, Robert E. (B)
Douzinas, N. (C)
Earle, Murdock Mack (B)
Faust, William (B)
Forsyth, James (B)
Loskarn, George B. (B)
Prevas, Peter John (C)
Smith, J. F. (B)
Waggner, George M. (B)
Watson, Morris (C)

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Nelsen, Ralph C. (B)
Rose, Henry (B)
Wellauer, Edward J. (B)

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Blickman, Bernard (B)
Bramley, Robert (C)
Chapin, Roderick K. (C)
McArdle, Linus L. (B)
McDonald, Morton T. (C)

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Cronin, Paul C. (B)
Ferguson, John Ashley (B)
Helm, William B. (C)
MacIntyre, Donald B. (C)
Shea, H. A. (C)
Sullivan, J. J. (C)
Weissert, Elwood W. (B)
Wurdack, Regis J. (C)
Zucco, Daniel J. (C)

ROCHESTER

Freese, Theodore F. (C)
Spotts, Francis E. (C)
Szablak, William T. (C)

SAN FRANCISCO

Lange, Kenneth W. (C)
Nicholl, Thomas Hill (C)

ST. LOUIS

Beckmann, Robert Joseph (C)
Brooker, Harry F. (C)
Edwards, William D. (C)
Hill, Stuart Gatch (C)
Kern, Raymond G. (C)
Wren, Vernon R. (C)

SOUTH TEXAS

Wagner, Louis G. (C)

TOLEDO

McCullough, L. W. (C)
Spevak, Leon M. (B)

TULSA

Wallace, C. H. (C)

WESTERN MASS.

Jaeger, L. W. (B)

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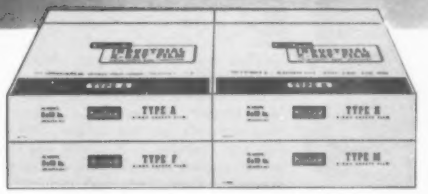
ANSWER:



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Type M—provides maximum radiographic sensitivity, under direct exposure or with lead-foil screens. It has extra-fine grain and, though speed is less than in Type A, it is adequate for light alloys at average kilovoltage and for much million-volt work.

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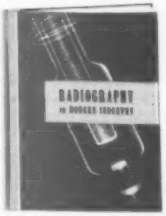
Type K—has medium contrast with high speed. Designed for gamma ray and x-ray work where highest possible speed is needed at available kilovoltage without use of calcium tungstate screens.



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WICHITA

Johnson, Emil E. (C)
Parker, Harry L. (D)

WORCESTER

Aptt, Sidney E. (B)
Greenwood, Donald (C)
Hobbs, James C. II (B)
Menconi, Elmer F. (C)
Polaski, Joseph Henry (C)
Sebastian, Albert (C)

NOT IN SECTIONS

Baldock, R. M. (B)
Baumgardner, G. E. (C)
Jackson, Auzville Jr. (D)
Kester, R. R. (B)
Waller, Jason J. (C)
Weber-Singer, John (B)

Members Reclassified

During month of February

HARTFORD

Light, John K. (C to B)

LOS ANGELES

Bryant, K. D. (C to B)

PHILADELPHIA

Oechsle, S. John (C to B)
Thomas, R. David, Jr. (C to B)

SECTION ACTIVITIES

Prepared by C. M. O'Leary

Anthony Wayne

The January meeting of the Anthony Wayne Section was held on the 28th, in the Auditorium of the Chamber of Commerce Building. Approximately eighty members and visitors were present. A very delicious buffet dinner was served at 6:30 P.M.

At the coffee session at 7:30 P.M., the group was entertained by Vernon B. Carr, a very talented local magician, who presented an unusually interesting program highlighted by his specialty act, "The Mystic Rope."

The principle speaker of the evening was Frank McGuire, Sales Engineer for The Linde Air Products Co., Chicago office. Mr. McGuire addressed the gathering on the subject, "Heliarc Welding and Its Applications." His talk, which traced the Inert-Gas Shielded Arc-Welding Process from its introduction in the welding of magnesium back in 1942 to its present scope, was very thought-provoking and the entire group showed considerable interest.

Mr. McGuire stressed the importance of proper jig fixtures; selection between helium and argon gases; a.-c. welders vs. d.-c. machines, emphasizing the difference in heats created in each; the flexibility of operations from heavy structural work to thin sheets. He clearly explained just how the torch works, further depicted by some very clear and illustrative slides, bringing out the importance of water cooling, light weight of torch and cables, control of gas with Flowmeter, automatic shut-off, etc.

At the conclusion of his talk, a question-and-answer session was held which proved that everyone was impressed by Mr. McGuire's discourse since many questions were fired at him by a large percentage of the group. Mr. McGuire had very straightforward and logical answers to the various queries and his replies were greatly appreciated due to their simplicity, directness and the use of common, everyday layman's language.

The February meeting was held at the Chamber of Commerce Building, Fort Wayne, Indiana, on the 25th with approximately eighty members and guests in attendance. The meeting was prefaced by an informal Buffet Dinner at 6:30 P.M. followed by a Coffee Session Entertainment Program consisting of two Color-Sound Movies, "Clean Water" and "The Atom Bomb Tests at Bikini." These were unusually interesting pictures furnished through the courtesy of General Electric Co., secured through the efforts of H. C. Smith.

Chairman Laws then called the formal meeting to order and introduced the speaker of the evening, C. B. Voldrich, Chief Welding Engineer of the Battelle Memorial Institute, Columbus, Ohio. Mr. Voldrich first extended greetings to this new Section from the Columbus, Ohio Section, which is celebrating its tenth anniversary. He commended the Anthony Wayne Section on the good start they have made and urged them to keep up their efforts as he said they would find it a real hard job to keep going and growing.

His subject for the evening was "The Weldability of Steel" which he stated was mostly a matter of costs as you can weld most anything you want to. The principal factor is being able to balance costs and the desirability of welding.

Some of the most important and interesting points covered by Mr. Voldrich were the importance of preheat, the securing of proper ductility, the hardness in the heat-affected zone, the difference between annealing and homogenization, and the direction properties of steel plate and their effect on welded joints. His talk was very clearly illustrated by the use of some unusually good picture slides.

Following his talk, a Question-and-Answer Session was held during which some very interesting points were very thoroughly discussed. Everyone agreed that Mr. Voldrich knew his subject and gave him their undivided attention all through the meeting.

Chairman Laws then declared the regular meeting adjourned but invited the group to stay afterward and enjoy some actual motion pictures of the surrender of Japan.

Birmingham

The March dinner meeting of the Birmingham Section was held on the 3rd at Hooper's Cafe. Speaker was H. T. Herbst, Development Engineer, The Linde Air Products Co., Newark, N. J. Much interest was shown in Mr. Herbst's talk on the Applications and Development of the Heliare Welding Process, and the discussion that followed. An interesting high-speed film was shown that clearly illustrated the different arc characteristics for a.-c., d.-c. straight and d.-c. reverse polarity for Heliarc welding.

Bridgeport

Monthly dinner meeting was held on February 17th at the Candlelite Restaurant. No dinner speaker. Technical speaker was A. N. Kugler, Mechanical Engineer of the Technical Sales Division of the Air Reduction Sales Co., New York. Mr. Kugler presented an interesting, clear-cut talk on the subject, "Welded Jigs and Fixtures." A movie was shown in conjunction with the talk on Inert-Arc Welding. Both were well received.

Chattanooga

"Oxygen—A Basic Raw Material for Industry" was the subject of the technical session of the February 11th meeting. Seventy-five members and guests turned out for the annual joint meeting of the A.W.S. and the A.S.M.E. held at the Chattanooga Golf and Country Club.

W. B. Browning, who is Process Service Manager of The Linde Air Products Co., presented his subject in a nontechnical, interesting manner. Included in his talk were the history, methods of production and uses of oxygen.

The meeting, which was preceded by a dinner and social hour, was one of interest and entertainment. A good time was had by all.

Chicago

A complete review of every major phase of aluminum welding was given by G. O. Hoglund of the Aluminum Company of America, New Kensington, Pa., at the technical session of the Chicago meeting held on February 18th. More than 185 members and guests were present at the People's Gas Light and Coke Co. auditorium for the evening's activities.

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Gas, welding, brazing, metal-arc, atomic hydrogen, inert-arc and resistance welding of aluminum sections, plates and sheets were illustrated in some eighty slides which accompanied Mr. Hoglund's talk. High-speed color movies of the inert-gas-shielded arc were also shown.

Special emphasis was placed by Mr. Hoglund on the newer inert-arc methods, which he said were opening new avenues in design and production in many fields. On thick sections, he said, it is doubtful if the inert-arc is more economical or efficient than the metal-arc with a good coated electrode, because the latter method necessitates fewer passes and the cost of argon gas is eliminated.

At the close of his talk, several members of the audience asked Mr. Hoglund for possible solutions to certain problems about welding aluminum forgings and castings.

A leather wallet was presented to Mr. Hoglund in behalf of the local Section for his fine talk.

The victory of the Chicago team over Detroit to win the national championship in the "Quiz the Expert" contest at Detroit on February 11th was related by H. A. Goodwin. Members of the team were: C. L. Pfeiffer, consulting engineer; H. A. Goodwin, Bastian-Blessing Co.; Dr. John Parks, Armour Research Division, Illinois Institute of Technology, and T. B. Jefferson, Editor of *The Welding Engineer*, who acted as captain.

Activities of the "Fusioneers," the social organization of the local section, were described for prospective members by C. B. Dewees, who also announced coming meetings.

Before the technical session, two sound color movies, "Trout Fisherman's Paradise" and "Welcome to Southern California" (courtesy of Santa Fe Railroad) were shown.

The premeeting dinner was held at 6:00 P.M. at Burke's Grille and Restaurant.

Cleveland

Thomas J. Crawford, well-known consulting engineer, spoke at the March 9th meeting. The subject of his talk was "Resistance Welding Applications."

Mr. Crawford is best known in the Cleveland area for his work as Director of Research for the Youngstown District of Republic Steel Corp., which position he held for a number of years prior to 1944, when he went into private consulting work. He is an officer of the Detroit Section and a member of ASM.

"High Speed Photography" was the subject of the coffee talk given by J. J. McDevitt, Jr. He explained applications of the new camera which can take pictures up to the rate of 20,000 frames per second.

Colorado

Dinner meeting was held on February 15th in the Range View Room, Silver Wing Inn, Denver. Fifty members and guests were present at dinner and the meeting. Henry Wade, Engineer, Stearns Roger Mfg. Co., gave a very interesting talk on the removal of Nitrogen from Nat-

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An excellent film was shown entitled "Industrial Development of the Rocky Mountain Empire."

Columbus

Dinner meeting was held on February 11th at Fort Hayes Hotel, Columbus, Ohio. Orville T. Barnett of the Metal and Thermit Corp., New York, presented a very interesting and amusing talk on electrode classifications, entitled "Why Not a Universal Electrode." He explained some of the uses of the different electrodes under their A.W.S. specification numbers.

He was able to clarify the uses of many of the different types of electrodes in the minds of some of the members not already familiar with them. By comparing the different trade names of the same A.W.S. Classification he was able to inject considerable amusement and comment from the audience.

R. R. Grant, Chairman, paid tribute to the Secretary-Treasurer, George S. Herren, who died on January 28th, after eleven years in this capacity. The new Secretary, Solon MacDonald, and the new Treasurer, Carl Alf, were introduced.

Dayton

February meeting of the Dayton Section was held on the 23rd in the Engineers Club. Speaker was H. C. Linde of the Air Reduction Sales Co., Supervisor of Technical Sales, Dayton. Mr. Linde's subject "Safe Practices for Welding and Cutting" was of interest to all.

There was also a "live" demonstration and a brief sketch on the history and physical properties of liquid air, conducted by Al Mealy, of Airco.

In addition, John Blankenbuehler, presented the film "Unfinished Business" projected by United States Steel Corp.

Detroit

The fifth meeting of the season was held Friday, January 14th, at the Engineering Society of Detroit in the small auditorium.

One hundred and thirty-five people heard Dr. W. D. Doty, Welding Metallurgist, Illinois Steel Corp., present a paper on the Metallurgy of Ferrous Welding. This paper was written by Dr. R. H. Aborn, Assistant Director of the Research Laboratory, U. S. Steel Corp. Paper was rendered very well and illustrated by numerous slides. Dr. Aborn was unable to present the paper because of illness and asked Dr. Doty, who had been previously associated with him in the U. S. Steel Laboratory, to read it for him.

Six Sections and national headquarters were represented in the attendance at Detroit's "Intersectional Quiz the Experts Night" held February 11th. The meeting proved to be a fast moving matching of wits by teams from Chicago, Western Michigan, Anthony Wayne and Detroit Sections.

So interested were the contestants and the audience in the answers to the varied welding questions presented, that the meeting had to be forcibly closed to permit compliance with the 11:00 P.M. closing rule of the Engineering Society of Detroit.

Chicago's team with T. B. Jefferson, Captain, Editor of *The Welding Engineer* and Secretary of Chicago Section; C. L. Pfeiffer, Consulting Engineer; Dr. John M. Parks, Armour Research Division, Illinois Institute of Technology; and H. A. Goodwin, Bastian-Blessing Co., won the title of Intersectional Experts. They had pointed out at the start that their title of International Champions, won a year ago, was not at stake since this was Intersectional.

Second place went to Detroit's team with Jack Ogden, Captain, Fisher Body Division, General Motors Corp.; C. E. Jamieson, Progressive Welder Company; E. H. Horton, Horton Welding Co.; and A. Fullenwider, Midland Steel Products Co.

Third place to Western Michigan with R. E. Kemp, Captain, American Seating Co.; Ottis M. Flenar, Rudd Manufacturing Co.; Clarence Lonkenau, National Cylinder Gas Co.; and E. Y. Bunting, Kilpatrick and Martin.

Fourth place, although very close in points to second and third, went to our newest A.W.S. Section, Anthony Wayne of Fort Wayne, Indiana. Their team was Virgil Beck, Beck Welding Co.; Carl L. Gavy, K & G Mfg. Co.; Harry M. Johnston, Wayne Welding Supply Co., Inc.; and Mark Clark, Wayne Welding Supply Co., Inc.

John F. Randall, Ford Motor Co., acted as moderator.

Judging was done by J. J. Chyle, A. O. Smith Corp., Milwaukee Section; Sam Snell, Odland Iron Works, Inc., Toledo Section; and by Joe Magrath from national headquarters.

The Saginaw Valley Division had a very interesting trip through the Baker-Perkins Plant at Saginaw on February 10th and saw some enormous baking ovens and stainless steel mixing bowls. The trip was arranged by Frank Cherry and was made through the courtesy of the management of Baker-Perkins, Inc.

Indiana

The January 21st dinner meeting was held at Bulkley's Restaurant in Cumberland, Indiana. A brief talk on the membership drive was made by Ray Wirt.

Technical speaker was A. N. Kugler of the Research Division, Air Reduction Sales Co., New York. Mr. Kugler's subject presentation on Helio Welding was of general interest to all. Fifty-six members and guests were present, some of which took part in the discussion of Mr. Kugler's presentation.

Two visitors were present from the Cincinnati Section and two from Purdue University. All guests were registered.

At the February 25th meeting held in the same place, Ray Wirt reported on the Section Meeting at Purdue University at which all Sections in the district were represented except South Bend and Tri-City. Mr. Wirt also reported on the membership drive and four new members were introduced.

An actual demonstration of welding technique required in the welding of zinc base die castings was given by V. A. Henry, Chief Welding Engineer, Bendix Products Div., Bendix Aviation Corp., South Bend. Mr. Henry showed anyone who was willing to try how to do the welding operation by actually handing them the torch and then showing them how it is done.

Fifty members and guests were present, about a third of whom participated in the discussion.

Los Angeles

Thursday evening, February 17th, the Los Angeles Section held its regular monthly dinner meeting with 85 members and guests attending. The speaker was George Palmer, Assistant Sales Manager, Sciaky Bros., Inc. The subject of Mr. Palmer's talk was "Three-Phase Resistance Welding Machines." Electrical circuits and apparatus employed to produce balanced loads, low power input and advantageous timing cycles were described in detail. Operational characteristics and their relationship to reduced maintenance costs and increased production rates were presented verbally and visually with the assistance of slides. Applications in the welding of metals dissimilar in material or thicknesses were discussed. Numerous questions on design, operation and application asked by the group were concisely and clearly answered.

Concluding feature of the program consisted of showing the interesting sound picture "Three Thousand Pounds." This color film presented by District Steel & Equipment Co., local representatives of Taylor Wharton Iron & Steel Co., depicted the manufacture of high-pressure compressed gas cylinders by piercing and drawing.

Louisville

F. Emery Garriott, Manager of Weld rod Dept., Ampco Metal, Inc., Milwaukee, Wis., was guest speaker at the February 22nd meeting and talked on the subject, "Welding With Bronze Electrodes." His talk was illustrated with lantern slides of data charts on bronze electrodes and photographs of weldments which had been successfully welded or overlaid with these electrodes.

Mr. Garriott discussed the various types of bronze electrodes available for the welding of copper base ferritic metals and a large variety of dissimilar metals. The preheats were listed and mention was made of special precautions to be taken in the welding of certain alloys.

A discussion followed the talk and after the showing of a sound and color movie, "Golden Horizons," produced by Ampco Metal, Inc., a dutch lunch was served.

Mahoning Valley

A joint meeting was held on February 17th at El Rio Restaurant, Warren, Ohio, between the Warren Chapter of the American Society for Metals and the A.W.S Mahoning Valley Section.

"Steel Processing" was the subject pre-

sented by H. W. McQuaid, who has specialized in the study of the relation between steelmaking practice and the properties of steels after processing. Mr. McQuaid collaborated in the development of the carburizing test later known as the McQuaid-Ehn test. Slides were shown in conjunction with the paper which concerned economy in the manufacture of steel.

Michiana

On February 17th the Michiana Section was favored with a talk on "Recent Developments in Resistance Welding," by William Cain, vice-president in charge of sales of the Sciaky Brothers Co., Chicago.

Mr. Cain's remarks were limited to spot, projection and seam welding. He pointed out the basic principles of these three types and then listed some of the special methods of getting current where you need it, for instance, series welding, the "push-pull" hook-up, etc. The bulk of the welders now being sold, he said, are those built to do one special job quickly, efficiently, and with a minimum of man power. This is being done as one of the few ways left to cut costs on such consumer products as autos, refrigerators, etc. Such machines are usually quite large and consequently their place is in large industry.

Most of these welders are being built along the lines of the big presses, and are so designed to fit right in a production line, many being made so that the line can go across the bed from side to side, or through it from front to back. He described the development of electrical circuits, culminating in the present design of "package" units, wherein the total of welds made are divided into groups of 4 to 8 spots which are fired by one transformer.

Mr. Cain also described the three phase welders and listed their advantages and disadvantages.

Milwaukee

The last two lectures in the Educational Program was presented on February 7th and 14th. E. Brekelbaum of Harnischfeger Corp. talked on Welding of Structural Steel at the meeting on the 7th. One of the significant points covered in this interesting talk was the general tendency to over-weld structural steel fabrications.

G. Leupold of the A. O. Smith Corp. gave the last lecture and discussed principally submerged arc welding. The influence of voltage, current and speed of travel on the shape of the weld nugget was covered quite fully.

Attendance at the last two meetings fell off slightly, but good attendance throughout the five talks indicates that the program is serving a good purpose.

The Section meeting for February held on the 25th was addressed by Orville T. Barnett, District Sales Manager, Welding Division, Metal & Thermit Corp., Newark, N. J., who had as his topic "Lime-Ferritic Electrodes." Mr. Barnett discussed in some detail the mechanical properties of welds made with this type of electrode and paid special attention to impact properties at both normal and low temperatures. Arc characteristics were also discussed and the speaker pointed out the necessity for holding a short arc for the best results. The usefulness of this type of electrode for welding high carbon steels and high sulphur steels and for joints that are to be subsequently enameled was also covered in this very interesting talk.

The after-dinner entertainment was movies of the 1948 World Series games.

New Jersey

R. David Thomas, Jr., of the Arcos Corp., was scheduled to speak at the February 15th meeting but was unable to attend because of an accident which hospitalized him. The New Jersey Section hopes that he has fully recovered and that they may benefit by his presence in the near future.

O. T. Barnett of the Metal & Thermit Corp. took over the speaker's duties in a most able fashion. Mr. Barnett has spoken before numerous other Sections of the SOCIETY and upon this occasion discussed Lime Base Electrode Coatings for Mild Steels and Popular Stainless Steel Electrodes.

The use of lime base coatings has made it possible to weld many types of structures and steels that had previously given trouble due to cracking. The lime type electrodes simplify the welding of sulphur steels and steels of high hardenability and reduce difficulties on parts which are subsequently porcelain enameled.

Titania base electrodes are preferred in some applications because of the smoother and more concave deposit, smoother arc and ability to weld with a. c. as well as d. c.

The concluding part of Mr. Barnett's talk covered stainless steel electrodes and their characteristics. The numbering system was described as follows: the first three numerals indicate the type of steel; the last two indicate the welding positions and type coating.

The April meeting is scheduled for April 19th. Dinner at 6:30 P.M. Meeting at 8:00 P.M. Hotel Essex House, Newark, N. J. Subject: "The Control and Inspection of Alloy Welding." Speaker: O. R. Carpenter, Babcock & Wilcox Co., Barberton, Ohio.

New York

At the annual joint meeting with the Society of Naval Architects and Marine Engineers, the New York Section heard J. Lyell Wilson, Research Director, American Bureau of Shipping, speak on "Welding in Shipbuilding" at the Columbia University Club on Friday, February 28th.

Mr. Wilson pointed out that much of the early troubles with welding in shipbuilding were caused by temporary expedients because of the lack of time to conduct thorough investigations. He showed, for example, that parts formerly riveted were being welded without any change in design. Using hatch corners for instance, he showed the evolution of hatch corner designs through investigations in structural design for welding. He also discussed the point that attention must be given to many factors previously regarded as unimportant, such as the specification of additional physical properties for the steel to be used for welded ships. Mr. Wilson's talk was illustrated with slides showing the evolution of hatch corner designs over a period of years.

As usual, this joint meeting was one of the most enjoyable of the year. Over 250 members of the two societies were present. William Jupp, Chairman of the Metropolitan Section of the S.N.A.M.E., introduced the speaker and conducted the discussion following Mr. Wilson's talk. Arrangements for the meeting were made by M. J. Giraldi, member of the Executive Committee of the New York Section, A.W.S., and also a member of the S.N.A.M.E.

Niagara Frontier

A joint meeting with the Niagara Frontier Society of Industrial Engineers was held at the John Maxwell Post, V.F.W., Buffalo, N. Y., on January 5th. Approximately 180 members and guests were present. The usual dinner and social hour preceded the technical session.

E. C. Brekelbaum, Executive Engineer, Harnischfeger Corp., Milwaukee, was the main speaker and presented his subject, "Production Problems and Production Control as Applied to Incentive Systems," in an excellent manner. He described his Company's incentive system as they now apply it to welded fabrication in their own shops. This plan has been widely discussed throughout the welding industry and has greatly aided increased production at Harnischfeger Corp. by providing adequate means of control as well as recognition to each of the groups on the production team, namely, management, designers, engineers and welders. The fact that welders agreed wholeheartedly with the plan and cooperated with management during its establishment created a very good impression among those present and stimulated considerable discussion at the conclusion of the talk.

A joint meeting with the Buffalo Chapter of the American Society for Quality Control was held at the Hotel Touraine, Buffalo, N. Y., on February 18th. Approximately 150 members and guests were present. The usual dinner and social hour preceded the technical session.

R. S. Inglis, Supervisor of Quality Control and Inspection Division, General Electric Co., Switchgear Division, Philadelphia, Pa., delivered the main topic of the evening. He was aided during his talk on "Quality Control Methods Applied to Resistance Welding" by O. C. Frederick, Head of the Welding Laboratory.

Mr. Inglis described the extensive program of development which preceded the final setup now used to assure the necessary standard of quality in their finished products. Special test coupons of welded sections and testing machines were designed and test coupons are continually removed from various points in the production line. Such a setup was felt to be necessary in order to insure against failures on the part of the welding operators. Full use is also made of electronic controls to insure further against weld failures and to make the welding operations more automatic in nature. All incoming materials are

Typical repair on 275-hp. Diesel truck engine. A broken engine block was repaired by applying a patch with Ni-Rod welding electrodes. Fourteen months later, the block is still in service.

IN the open-pit nickel mines at Copper Cliff, Ontario, Diesel trucks haul 32-ton ore loads up steep, winding roadways. After several thousand hours of this severe service, failures develop in castings and engine parts.

A serious type of failure is the cracking of cast iron cylinder blocks. New engine blocks cost $644.09 each ... a price that makes the prospect of repairs very attractive.

In the past, damaged blocks have been repaired by oxy-acetylene welding, a relatively critical and time-consuming process. But recently, repairs have been made with metal-arc welds, using Ni-Rod* electrodes. This technique has been completely successful, and the use of Ni-Rod electrodes has given excellent weld quality and has cut welding time.

Here are three typical case reports on repairs made with Ni-Rod:

"1. Block broke in crank chamber after 9381 hours of service. A patch was welded in with Ni-Rod. Since the repair, the block has operated 2064 hours and is still in good condition. Cost of welding was $12.75.

"2. Crank shaft failed after 1746 hours. The broken end engaged the main bearing shells, turning them in the block, heavily scoring the saddle. Repairs were made by machining the bearing area to .100-inch oversize, building up with Ni-Rod, and finally machining to correct size. This prolonged the engine life by 4087 hours. Cost of the entire repair was $40.60.

"3. Crank shaft failed after 4540 hours, causing damage similar to that described in Case 2, above, and was repaired the same way. The engine is still in operation 1369 hours after the repair. The cost of repair was $42.50."

SAVED . . .
HOURS MORE SERVICE
from truck engines repaired with NI-ROD

The three blocks described have a total replacement value of $1,932.27. Subtracting the repair costs, there is a net saving of $1,836.42, and a gain of more than 7520 hours of operating service.

Maintenance stories such as these...three of hundreds in our files...show why 4 out of 5 shops re-order Ni-Rod, once they've tried it. If you are not yet familiar with Ni-Rod's outstanding advantages, why not order a package today? Your nearest INCO distributor stocks Ni-Rod in 3/32", 1/8", 5/32", and 3/16" diameters.

Send for your free copy of: *"NI-ROD—A New Electrode for Any Cast Iron Welding."*

The Frood Stobie Mine, Copper Cliff, Ontario, operated by The International Nickel Company of Canada, Ltd.

One of the Diesel-powered trucks used for ore hauling at the Frood Stobie Mine. The truck maintenance department has standardized on Ni-Rod electrodes for cast iron repairs.

HERE'S WHAT NI-ROD GIVES YOU

in performance

- Stable arc in all positions
- Smooth bead contour
- Excellent wash
- Easy slag removal
- Preheating seldom required
- Works on both AC and DC

in weld quality

- High-strength deposit
- Easy machinability
- Thorough fusion
- Freedom from cracks and porosity
- Close color match

in usefulness

- General repair and maintenance of cast iron parts, including build-up of worn surfaces
- Quick remedy for minor flaws in new castings
- Correction of machining errors
- Assembling cast iron to steel

EMBLEM OF SERVICE INCO NI-ROD TRADE MARK

THE INTERNATIONAL NICKEL COMPANY, INC.

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checked for faulty composition and welding properties in the Welding Laboratory.

The meeting originally scheduled with the American Foundrymen's Association has been cancelled and the Section now hopes to have the meeting scheduled for May in April instead. Further, it is planned to end the season with the May meeting, which is to be the Annual Party and installation of officers. Plans are now being made to make this a Ladies Night as well.

Approximately 17 members from Buffalo and vicinity attended the first meeting of the Olean Subsection at the Castle Inn, Olean, N. Y. Approximately 60 men were present from Southwestern New York and Northern Pennsylvania to serve as a nucleus for the new group. Talks were given by J. G. Magrath, Executive Secretary of the A.W.S., C. E. Jackson, I. Morrison, and C. H. Jennings, who presented a technical talk on "Design for Welding." An initial activation organization was formed consisting of a voluntary executive committee and interim officers and appointees.

The interim officers are: Chairman—R. H. Livingston, 1st Vice-Chairman—C. G. Thomas, 2nd Vice-Chairman—F. Schnable, Treasurer—H. C. Bender, Secretary—F. M. Summers. Permanent officers will be elected later.

Northern New York

Meeting of the Northern New York Section was held on Thursday, February 24th, at Union College in Schenectady. Bela Ronay, Superintendent of the Welding Laboratory of the U. S. Naval Engineering Experiment Station at Annapolis, was the principal speaker. The subject of his talk was "New Trends in the Development of Welding Electrodes." Mr. Ronay discussed a number of interesting welding problems in which electrodes play an important role. The following topics were treated from the electrode point of view: designing on basis of endurance limit rather than on basis of safety factor, differences in expansion between weld metal and base metal, vibration damping capacity of weld metal, graphitization of steels at elevated temperatures, welding of gray cast iron, heat treatment of weld metal and low yield strength in weld metal. Mr. Ronay's talk was very interesting and it was well received by an audience which included a number of men who came all the way from Pittsfiled, Mass., for the occasion.

The April 28th meeting will be held in Pittsfield. Speaker will be R. W. Tuthill of the General Electric Co.

Annual Meeting of the Section will be held on May 26th. Subject will be Inert-Arc Welding.

Northwestern Pennsylvania

February 23rd meeting of this Section was held in the G. E. Community Center, Erie, Pa. Dinner speaker was J. G. Magrath, Executive Secretary of the A.W.S. Mr. Magrath discussed the new JOURNAL pattern and made a request for material for THE WELDING JOURNAL. He also stressed the importance of attendance of all members regardless of subject. Mr. Magrath's remarks were very well received.

Technical speakers were George M. Trefts III and J. M. Tippett. They spoke on the subject "Submerged Melt-Welding Process for Fabrication of Pressure Vessels."

The Union Iron Works, Erie, Pa., was host for a social half hour prior to dinner.

A plant visit was made in the afternoon to the Hammermill Paper Co., Erie, Pa.

Oklahoma City

Roger J. Metzler of Handy & Harman spoke on "Design for Silver Alloy Brazing" at the February 9th meeting. Mr. Metzler's talk coupled with his instructive slides and his Handy & Harman color film were excellently received.

After the meeting, the regular social session took place at which sandwiches and coffee were served.

The Governor of the State of Oklahoma proclaimed the week of January 31st through February 5th as "Engineers' Week in Oklahoma." The Section invited the Oklahoma Society of Professional Engineers to send them a speaker who would open the meeting with a very short talk and as a result, they sent Wm. E. Bleakley, the local Executive Secretary. It is hoped that such cooperation will foster a greater spirit of friendliness in the future.

Pascagoula

The Pascagoula Section held its monthly dinner meeting on Wednesday, February 9th, at the Pascagoula Country Club with thirty-six in attendance, representing industries on the Mississippi and Alabama Gulf Coasts.

The coffee speaker was T. J. Tyson, Plant Engineer at the Ingalls Shipbuilding Corp., who spoke on "Maintenance in Relation to Welding."

Mr. Tyson spoke of the numerous advances in hand welding, which were of assistance to maintenance in maintaining industry. He pointed out the numerous problems encountered in keeping several thousand motor generator and a.-c. transformer units and their auxiliary equipment in first-class operating condition.

The technical speaker for the evening was W. F. Hiser, engineer for the Humble Oil and Refining Co., who spoke on "Welding in Relation to Offshore Drilling."

Mr. Hiser is the chief engineer in charge of construction for the Humble Oil Co. in Mississippi. He is with the Humble Oil Company's marine Equipment Division, which constructs and maintains all marine equipment including the offshore drilling equipment used by this company.

Mr. Hiser spoke of the numerous problems involved in designing and constructing equipment for the new operations of drilling for oil offshore. He had slides showing the types of equipment which are now in operation and under construction. He pointed out a number of welding problems involved in the marine field which were odd in nature, being characteristics of the oil industry such as the very high pressure served piping made from various types of alloys. Mr. Hiser pointed out the infancy of this operation and some of the inadequacy of the present equipment as a challenge for welded design to furnish the equipment necessary. He pointed out the millions of dollars being spent at this time and the unlimited horizons of the future in this field.

Another meeting was held on Monday, February 28th, at the Pascagoula Country Club. Dinner speaker was R. H. Macy. Speaker at the technical session was H. T. Herbst, Development Engineer, The Linde Air Products Co., Newark, N. J. Mr. Herbst presented a clear-cut, interesting paper on "Production Application for Inert Gas-Shielded Arc Welding." An ultra high-speed film on Inert-Gas Arc Welding was also shown.

Philadelphia

The annual joint meeting on February 21st of the Philadelphia Section of the A.W.S. and the Philadelphia Section of the Society of Naval Architects and Marine Engineers was as usual an outstanding success. One hundred and three members and guests were present.

R. W. Tuthill, Development Engineer, General Electric Co., Holyoke, Mass., covered the subject "Inert Arc Welding as Applied to Shipbuilding," in a thorough manner, ranging from the technical aspects of the process to its practical applications.

Following the example of the Naval Architects, two prepared discussions were presented before throwing the meeting open for discussion from the floor. Both C. A. Loomis, Bureau of Ships, Washington, D. C., and W. H. Wooding, Philadelphia Naval Shipyard, contributed additional valuable information on the use of this process and started off the general discussion in a fine fashion.

The lively discussion of this process exhibited the keen interest concerning its use in both the welding and shipbuilding industries.

Pittsburgh

The regular monthly dinner meeting was held on February 16th at Mellon Institute. Dinner was in the Hunt Room-Webster Hall Hotel. Lecture was delivered by Wm. J. Farrell, Chief Engineer, Sciaky Bros., Chicago. Questions were answered by both Mr. Farrell and David Sciaky, President, Sciaky Bros., Inc. Their subject was "Resistance Welding as Applied to Low Pressure Vessels and Structural Welding." Eighty members and guests were present to hear this interesting lecture and participate in the discussion.

A very good film was shown through the courtesy of the General Electric Co. entitled "The Power by Which We Live."

Puget Sound

The February meeting held on the 23rd was scheduled to coincide with visit to Seattle of the First Vice-President, O. B. J. Fraser.

A luncheon meeting of the officers and Executive Committee of the Section was arranged at the College Club at noon. This developed into a very interesting

meeting with lively discussions of various phases of SOCIETY activities.

The dinner meeting preceded by a cocktail hour was held at 6:00 P.M. at the Gowman Hotel in Seattle. The dinner meeting was well attended, with 51 present. A keen interest was shown in Mr. Fraser's remarks concerning the welfare of the SOCIETY and what can be done to increase membership and bring all delinquents back into good standing.

About 65 attended the technical session which followed the dinner. Marvin Stern's talk on "Weldability of High-Temperature Resisting Alloy Sheet Steels was very interesting and well received. His talk was accompanied by a series of lantern slides based on the many tests and experiments conducted by the Boeing Airplane Co., with which he is connected as Welding Engineer, to determine the best alloys and the best methods of welding to get the best performance in various parts of jet engines, rockets, guided missiles and parts of other aircraft engines. The many questions following his talk showed the general interest that this type of welding presents.

Bethlehem's sound film "The Making of Alloy Steels" kept the group interested for another forty-five minutes. This picture was shown through the courtesy of the Bethlehem Pacific Coast Steel Corp. and was presented by John G. White, Jr., and Traverse Foxworth.

Rochester

On Monday, February 21st, the Rochester Section held its regular monthly meeting at the University of Rochester.

Winfield Van Horn, Supt. of Station 3, Rochester Gas & Electric Corp., spoke on "Welded Repairs on Power Plant Equipment." Mr. Van Horn supplemented his talk with slides taken at the Power Plant and pointed out where various repairs to generating and coal handling equipment are made. Pictures showing the comparison of equipment, installed thirty-five years ago, with new installations were also projected.

Preceding Mr. Van Horn's talk, a movie entitled "Advantages of A.-C. Welding" was shown. This movie was produced by the Westinghouse Electric Corp.

J. G. Magrath, Executive Secretary, and George Trafts, District Vice-President, were present at the meeting.

The Educational Program, conducted on the first Monday of each month by William J. Conley, now has an enrollment of 85.

San Francisco

February dinner meeting was held on the 28th at the Engineers Club. Seventy members and guests were present to hear J. H. Landells, Radio Sales Supervisor of the Westinghouse Electric Corp., speak on "Some Economic Aspects of Television."

Outlining the growth of the medium in the past year and a half, Mr. Landells reported that present investment in television sets is a half billion dollars. Problems which must be overcome in developing TV now are that "nobody knows yet what constitutes a good television program," and broadcasting costs to the sponsor are approximately 20 times as much as for an AM program.

For wider distribution of programs, Mr. Landells reported the co-axial cable transmission is not wide enough, and that it is too expensive.

Westinghouse experiments with the Glenn L. Martin Co. have found an answer to the transmission problem in an airplane carrying a transmitter, he said, reporting that 14 planes, each carrying four transmitters could furnish service in four channels for 72% of the nation's population, throwing out wider beams and requiring less power than ground stations.

Mr. Landells' background of 15 years in the radio broadcasting industry, 3 years of teaching of radio engineering at Stanford University and 2 years as radar instructor in the U. S. Marine Corps certainly qualifies him as one of the foremost men in this field.

Toledo

The Toledo Section meeting on Dec. 8, 1948, in the Commodore Perry Hotel was of interest to all those who work with nickel or nickel alloys. It was sponsored by Williams & Company, Inc., Toledo Plant, of which George Schmitt is manager.

The speaker, R. M. Wilson, Jr., Mechanical Engineer, the International Nickel Co., New York, was given a good send off by Mr. Schmitt. Also present was E. A. Tschop, Sales Engineer from the New York office of the same company.

The speaker's topic was "Welding of nickel and High Nickel Alloys." Slides were used in the talk for better and easier comprehension. A high concern was manifested by the 33 in attendance concerning these particular welding problems.

The meeting on January 12th was fascinating to those present, even though it did not concern welding. Gordon Anderson, Research Engineer with Dow Chemical Co. of Midland, Mich., used for his talk the title "Chemistry's New Dimensions."

He told a good deal about the history of his employer, the Dow Chemical Co., and the many products which the company produces and markets.

On Wednesday, February 9th, in the Commodore Perry Hotel, members and guests of the Toledo Section heard a most timely discourse.

The speaker, W. R. Plummer, General Sales Manager of the Progressive Welder Company, Detroit, gave very interesting inside information on "Design for Resistance Welding."

A narrated color film "This is Resistance Welding," explained the fundamental mechanics of spot, seam and projection welding, besides showing actual production welding machine installations.

For further clearness and understanding of this art the speaker also made use of slides. It was easy to see how different designs of a welded structure affect the tooling necessary for any given welding machine to be used.

He pointed out how the welding machine manufacturers can give valuable tips on correct design if consulted before the design is begun.

A 10 karat gold A.W.S. emblem was presented to V. L. Farnsworth by Chairman Newman for his outstanding services to the Toledo Section.

Tri-State

Fifty-six members and guests were present at the dinner meeting held on January 27 at the Vendome Hotel, Evansville, Ind. "Arc Welding Electrodes" was the subject of L. K. Stringham's address of The Lincoln Electric Co.

February 24th dinner meeting held at the same place was attended by 33. Charles Bruno of Reynolds Metals spoke on the subject "Aluminum Welding." A film on the same subject was shown in conjunction with the talk. Both were well received.

Washington, D. C.

Great interest was displayed in the talk by Dr. G. E. Claussen on "Arc Welding Electrodes" presented at the February 15th dinner meeting. High-speed motion pictures of the welding are were shown in connection with the presentation and were well received. Dr. Claussen is associated with the Reid Avery Company, Inc.

Refreshments of coffee and doughnuts were served.

Western Massachusetts

The Western Massachusetts Section held a dinner meeting at Blake's Restaurant, Springfield, Mass., on February 8th. Thirty-five members and guests attended while Jim Craig of The Linde Air Products Co. spoke on the characteristics of the inert-gas shielded arc. Mr. Craig's talk was supplemented by slow-motion movies on this process to illustrate the effect of reverse and straight polarity gas shielded arc welding.

One important feature of inert-gas shielded arc welding is that the weld puddle, the arc and the tungsten welding rod are all shielded by an inert gas and hence do not require flux for protection. The head of the welding torch is water-cooled and equipped with orifices in the cup to allow a flow of gas to shield the puddle from the nitrogen and oxygen of the atmosphere. Water may be used not only to cool the head, but also to conduct the current. If the water supply fails, current will cease to flow; thereby preventing the head from being burned out.

The above was one of the many interesting facts brought out by this talk. The talk and movies were very well received and were followed by an interesting and lively discussion.

Wichita

A joint meeting with the American Society for Metals was held on February 15th at the Knights of Columbus Hall. Dr. Lloyd McKinley, Head of Chemistry, Wichita University, discussed Hard Chrome Plating. A movie "Manufacture

of Wire Rope" was shown through the courtesy of the Colorado Fuel & Iron Co.

Worcester

The Worcester Section held a dinner meeting on February 28th at the Coronado Hotel, Worcester, Mass. Forty-six members and guests were present at the technical session to hear Jamison Moore of the Union Bag & Paper Co., Savannah, Ga., speak on the subject "Maintenance Welding." Mr. Moore is well qualified to talk on this subject. His many ideas, especially in methods were most interesting. The entire talk was practical throughout. Every phase of welding used in the field today is in operation at his plant in one capacity or another.

York-Central Pennsylvania

March 2nd meeting was held in the Engineering Society Building, York, Pa. Dinner at the Hotel Yorktowne. Fifty members and guests heard Wm. B. Hess, Engineer of Tests, Safe Harbor Power & Water Co., give a demonstration of the critical points in steel and their effect on welding.

The class in Construction Materials at Penn State Extension at York Junior College were present.

Canadian Welding Society

A Stump-the-Experts Night is scheduled by the Toronto Chapter for May 2nd.

The A.W.S. Section . . .

—A very important link in the National Society

The American Welding Society Section performs one of the Society's most important functions. It needs the support of every Member for its sustenance.

The Section is the "strength unit" of the Society. The Member is the "strength unit" of the Section. An active Member, Committee Member, or Officer makes it possible for the Section to have live meetings, larger membership, outstanding speakers, more educational courses and activities of interest. The Sections and the Society need Member activity to carry out an effective program, to aid in the development of technical and ethical standards for the welding industry.

The Section benefits the Member educationalwise. He meets local, sectional and national speakers of proved merit; men of trained and broad experience in every phase of welding, cutting and allied process activity; men who are explorers in modern research and development. He receives the benefit of the combined knowledge of all members of the Society. He participates in educational courses, pictures and inspection trips.

Through Section activity the Member benefits others. Without active Members the Section will cease to exist. The Member is asked to take part in the discussions; to project his ideas into its meetings; to register the value of his experience; to excite the minds of others with his problems; and to provide his answers to the problems of his Fellow Member. The Member's beneficial returns are in direct proportion to his cooperation and expended effort.

The Member becomes acquainted with economic developments affecting his company's operations; is made aware of ways and means for reducing welding, cutting and allied process operating costs; is kept abreast of the most recent developments in welding metallurgy methods, procedures and techniques affecting design construction and production; and is made acquainted with the best shop practices, the best materials, the proper codes, standards and specifications, types and styles of welding and safety rules.

Support your AWS Section

—a new edition of Welding Metallurgy

First published in 1940, this book has had several printings and has been distributed all over the world. To bring it up to date, Mr. G. E. Linnert has prepared an extensive revision so that the new edition will have about 500 pages—150 pages more than the first edition. Many new illustrations have been added to bring the total to 203.

Material has been added to cover the new processes such as inert gas metal-arc welding; material has been added to provide greater coverage of the stainless steels.

A list of books is given at the end of each chapter for those especially interested in the subject covered by that chapter. Questions for school use are grouped together at the end of the book; they can be used for home study as well.

Now being printed, *Welding Metallurgy* will be published this spring. The price will be $2.50 per copy. All members of the American Welding Society will receive a certificate entitling them to a copy of this book at the special price of $2.00; this will be mailed to you soon—watch for it.

WELDING RESEARCH COUNCIL

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American Institute of Mining and Metallurgical Engineers, American Society of Civil Engineers
American Society of Mechanical Engineers, and Society of Naval Architects and Marine Engineers

Supplement to The Welding Journal, April, 1949

Notch Sensitivity of Steel Evaluated by Tear Test

The evaluation of notch-sensitivity characteristics of steel by the tear test method and its application to quality control of ship plate. Data on rimmed, semikilled and fully killed steel in thicknesses up to 1 1/4 in.

by Noah A. Kahn and Emil A. Imbembo

Abstract

In previous papers,[1, 2] the authors described the Navy tear test method for evaluating the susceptibility of steel to cleavage fracture and discussed its application to a number of medium steel ship plate samples and its correlation with the results of large-scale plate tests. This paper presents and discusses data on the notch-sensitivity characteristics, as revealed by the tear test, of a number of additional plate steels consisting of rimmed, semikilled and fully killed medium steel in 1/2 and 3/4 in. as-rolled thicknesses (yield strength 30,000–35,000 psi.), "vanity-type" high-tensile steel in as-rolled thicknesses of 7/8, 1 and 1 1/4 in. (yield strength 50,000 psi. min.) and special high-yield alloy steels in thicknesses of 3/4 and 1 in. (heat treated to a minimum yield strength of 75,000 psi.).

The paper also discusses the effect of some variations in specimen geometry and plate thickness, effect of nitrogen content, and the applicability of the tear test method to quality control of ship plate and related structural steels.

INTRODUCTION

IN PAPERS presented before the 1947 Annual Meeting of the AMERICAN WELDING SOCIETY[1] and the 1948 Annual Meeting of the American Society for Testing Materials,[2] the authors described a laboratory-scale test method capable of evaluating the susceptibility of steel plate to brittle or cleavage-type fracture. The Navy tear test method, as it has been named, utilizes a specimen of the type shown in Fig. 1. It will be observed that the specimen is 3- x 5-in. x full plate thickness and is notched to provide for asymmetric loading in static tension with an initial eccentricity of 0.039 in. The specimen is loaded to complete failure under controlled temperature conditions at a cross-head speed of approximately 0.1 in. per minute. An automatic load-extension diagram is obtained for each specimen to complete failure. Characteristic load-extension diagrams obtained on medium steel plate

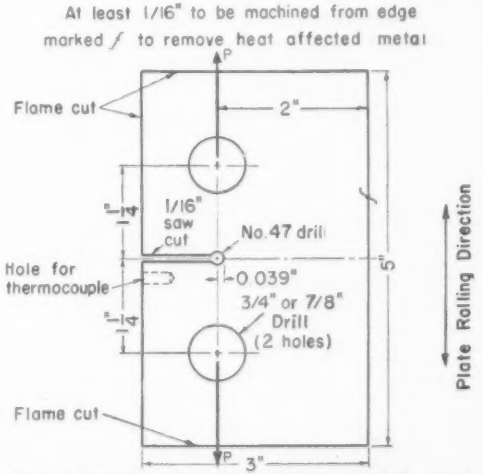

Fig. 1 Navy tear test plate specimen, keyhole notch
Note: P–P indicates direction of load application

Noah A. Kahn and Emil A. Imbembo are Consulting Metallurgist and Senior Metallurgist, respectively, Material Laboratory, New York Naval Shipyard, Brooklyn, N. Y.

The opinions or assertions contained herein are the private ones of the authors and are not to be construed as official or reflecting the views of the Navy Dept., the Naval Service at large or the Ship Structure Committee.

This paper was presented at the Twenty-Ninth Annual Meeting, A.W.S., Philadelphia, Pa., week of Oct. 24, 1948.

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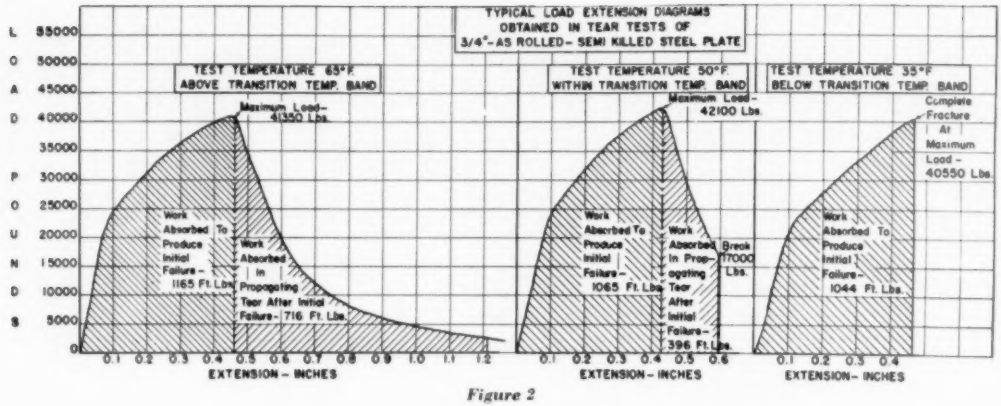
TYPICAL LOAD EXTENSION DIAGRAMS
OBTAINED IN TEAR TESTS OF
3/4"-AS ROLLED-SEMI KILLED STEEL PLATE
TEST TEMPERATURE 65°F
ABOVE TRANSITION TEMP. BAND
Maximum Load-
41350 Lbs.
Work Absorbed To Produce Initial Failure- 1165 Ft. Lbs.
Work Absorbed In Propagating Tear After Initial Failure- 716 Ft. Lbs.
TEST TEMPERATURE 50°F
WITHIN TRANSITION TEMP. BAND
Maximum Load-
42100 Lbs.
Work Absorbed To Produce Initial Failure- 1065 Ft. Lbs.
Work Absorbed In Propagating Tear After Initial Failure- 396 Ft. Lbs.
Break In Prop- agating 17000 Lbs.
TEST TEMPERATURE 35°F
BELOW TRANSITION TEMP. BAND
Complete Fracture At Maximum Load - 40550 Lbs.
Work Absorbed To Produce Initial Failure- 1044 Ft. Lbs.
LOAD - POUNDS
EXTENSION - INCHES
EXTENSION - INCHES
EXTENSION - INCHES

Figure 2

specimens tested at temperatures above, within and below the transition temperature region are shown in Fig. 2. The area to the left of the perpendicular erected at the point of maximum load represents the energy required to induce intital cracking while the area to the right represents the energy input to propagate the tear or crack from start to completion. The corresponding fractures are shown in Fig. 3. The fracture to the left is representative of a fully ductile, shear-type failure and is associated with a high energy value to propagate tearing (716 ft.-lb.). The fracture to the right is representative of a predominantly brittle, cleavage-type failure which is associated with an energy-to-propagate value of practically zero. The middle fracture represents an intermediate condition associated with failures occurring within the transition temperature region.

Results of a complete tear test series of a $^3/_4$-in. thick medium steel plate are presented in Fig. 4. It will be noted that the maximum load and the energy to start fracture are unaffected by the mode of fracture over the temperature range investigated. However, the energy to propagate fracture and the percentage of shear in the fracture are subject to a discontinuous and abrupt change over a temperature band which marks the transition from ductile, shear-type to brittle, cleavage-type fracture. The highest test temperature at which first evidence of marked scatter in the per cent shear and energy-to-propagate values occurred was designated as the start of transition. By arbitrary definition, the start of transition based on fracture evaluation was taken as the highest test temperature at which one or more specimens exhibited a shear area originating from the notch of less than 50% of the entire fracture area. Similarly, the start of transition based on energy evaluation was taken as the highest temperature at which one or more specimens showed an energy-to-propagate value of less than half of the energy level in the predominantly shear region. It is important to note that both methods of evaluation indicate the same temperature of start of transition. Further reference to transition temperature in this paper pertains to temperature at start of transition on the basis of the above definitions.

Tested at

65° F. *50° F.* *35° F.*

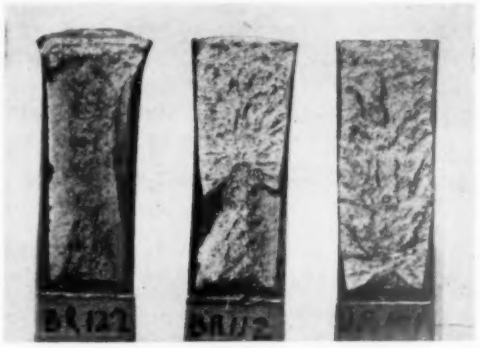

Fig. 3 Fractures of tear test specimens corresponding to diagrams of Fig. 2

COMPOSITION (PERCENT)	C	Mn	P	S	Si	Ni	Cr	Mo	Cu	Al	Sn	N
	.25	.49	.011	.045	.04	.03	.04	.004	.01	.004	—	.004

TENS. PROP. Y.P.-34090 T.S.-58640 ELONG. IN 8" (%)-33.4

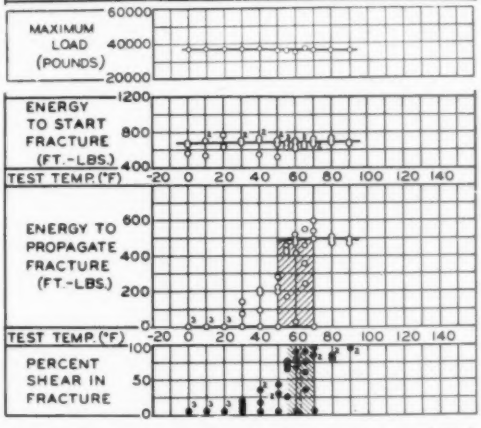

Fig. 4 Tear test properties of project Steel A; semikilled, as-rolled, $^3/_4$-in. plate

Table 1—Summary of Correlation Between Transition Temperature as Determined by Tear and 72-In. Wide-Plate Tests

STEEL	PROCESS	C %	Mn %	TEAR TEST TEMP AT START OF TRANSITION (a)	72" WIDE PLATE MEAN TRANSITION TEMP., °F (b)	ΔT (c)	Mn/C
H	FULLY-KILLED	.17	.78	50	20	+30	4.6
Br	SEMI-KILLED	.16	.76	60	33	+27	4.7
Dr	FULLY-KILLED	.19	.55	60	28	+32	2.9
Dn	FULLY-KILLED	.21	.55	70	30	+40	2.6
A	SEMI-KILLED	.25	.49	70	35	+35	2.0
C	SEMI-KILLED	.25	.51	135	90	+45	2.0
E	RIMMED	.23	.37	140	95	+45	1.6

NOTES (a) BASED ON BOTH FRACTURE AND ENERGY-TO-PROPAGATE EVALUATION.

(b) BASED ON VALUE OF TEMPERATURE CORRESPONDING TO AN ENERGY VALUE ON THE STEEPLY-SLOPING PART OF THE ENERGY-TEMPERTURE CURVE APPROXIMATELY HALF-WAY BETWEEN THE MAXIMUM AND MINIMUM ENERGY VALUES.

(c) DIFFERENTIAL BETWEEN TEAR TEST TEMPERATURE AT START OF TRANSITION AND MEAN TRANSITION TEMPERATURE OF WIDE PLATE TESTS.

The previous papers[1, 2] presented tear test characteristics of four rimmed, three semikilled and two fully killed medium steels and, in each instance, it was found that the Navy tear test method sharply defined the location of the transition temperature and revealed, in a marked manner, differences in the behavior of these steels with respect to their relative susceptibility to cleavage fracture. The method successfully brought out differences in the behavior of project steels *A* and *C*[1, 2] in a manner similar to the differences noted in the large-scale plate tests,[3,4] whereas no distinction between the two steels was observed from conventional static physical tests or Charpy notched-bar tests.[4]

It was also shown[2] that the tear test method rated the project steels in substantially the same order of relative tendency to shift from ductile to brittle behavior with decreasing test temperature as the large-scale, internally notched, plate tests, as indicated in Table 1. The tear test method indicates start of transition temperatures which are, in every case, from 30 to 40° F. higher than the mean transition temperatures as determined by the 72-in. wide plate tests.* Figure 5 is a representative plot showing the relative location of transition as derived from the tear and 72-in. wide-plate tests.

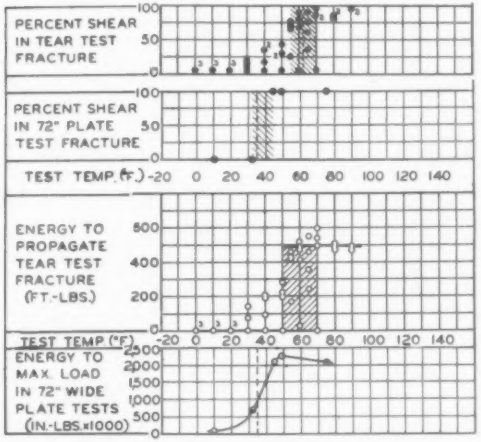
PERCENT SHEAR IN TEAR TEST FRACTURE
PERCENT SHEAR IN 72" PLATE TEST FRACTURE
TEST TEMP. (°F.) -20 0 20 40 60 80 100 120 140
ENERGY TO PROPAGATE TEAR TEST FRACTURE (FT.-LBS.)
TEST TEMP (°F)
ENERGY TO MAX. LOAD IN 72" WIDE PLATE TESTS (IN.-LBS.×1000)

Fig. 5 Location of transition ranges as defined by per cent of fracture in shear mode and by energy values as derived from 3- x 5-in. tear tests and 72-in. wide plate tests. Project Steel A

This paper presents data on the notch-sensitivity characteristics, as revealed by the tear test, of a number of rimmed, semikilled and fully killed medium steel plates in $^1/_2$- and $^3/_4$-in. as-rolled thicknesses (yield strength 30,000–35,000 psi.), "vanity-type" high-tensile steels in as-rolled thicknesses of $^7/_8$, 1 and $1^1/_4$ in. (yield strength 50,000 psi. min.), and special high-yield alloy steels in thicknesses of $^3/_4$ and 1 in. (heat treated to minimum yield strength of 75,000 psi.). The paper also discusses the effect of some variations in specimen geometry and plate thickness, effect of nitrogen content and the applicability of the tear test method to the quality control of ship plate and related structural steels.

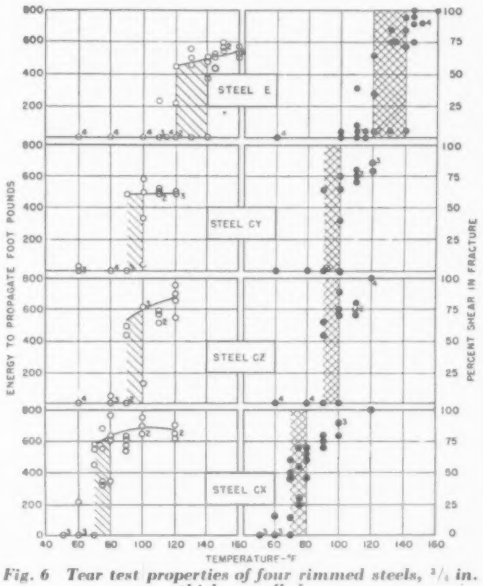

Fig. 6 Tear test properties of four rimmed steels, $^3/_4$ in. thick, as-rolled

APPLICATION OF NAVY TEAR TEST TO EVALUATION OF NOTCH-SENSITIVITY OF MEDIUM STRUCTURAL STEELS

The authors have discussed[2] the application of the Navy tear test to project steels A, B, C, D, E and H. Application of the tear test has been made to an additional number of medium steels for the purpose of investigating further the notch-sensitivity characteristics of this class of steel, some of the factors which influence the location of the transition temperature and the possible utilization of the tear test as a quality control

* A rather exhaustive series of 12-in. wide, internally notched, plate tests on these steels is in progress at Swarthmore College and further data on correlation will be available when those tests are completed.

method. A description of the medium steels investigated to date is given in Table 2. It is to be noted that the group includes four rimmed steels, eight semikilled steels and three fully killed steels.

Rimmed Steels

The four rimmed steels (E, CX, CY, CZ) investigated showed a range in carbon from 0.14 to 0.23%, manganese from 0.34 to 0.47%, yield from 30,950 to 37,340 psi. and tensile strength from 57,310 to 61,440 psi. Complete tear test properties of these steels were reported in a previous paper,[2] a summary graph of which is presented in Fig. 6. It is to be noted that the transition varies from 80° F. for Steel CX to 140° F. for project Steel E. The notch-sensitivity characteristics of the additional steels CX, CY and CZ serve to illustrate that project Steel E is not necessarily representative of rimming practice.

Semikilled Steels (3/4-in. Thickness)

The eight 3/4-in. thick, semikilled steels investigated showed a range in carbon from 0.14 to 0.25%, manganese from 0.49 to 0.93%, yield from 31,400 to 36,630 psi. and tensile strength from 56,980 to 66,000 psi. Complete tear test properties of project steels A, B and C were previously reported,[1, 2] and a summary of the tear test characteristics of the five additional "S" steels is shown in Fig. 7. The transition temperatures for these eight steels are as follows:

Item	*Steel*	*Temp. at start of transition, ° F.*	*C*	*Mn*	*Mn/C*
1	Project C	135	0.25	0.51	2.0
2	S19-62K	110	0.19	0.62	3.3
3	S14-70K	100	0.14	0.70	5.0
4	S20-62F	80	0.20	0.62	3.1
5	S18-93K	70	0.23	0.93	4.0
6	Project A	70	0.25	0.49	2.0
7	Project B	60	0.16	0.76	4.7
8	S18-93F	−20	0.18	0.93	5.2

The following additional observations are made in connection with Fig. 7 and the above tabulation:

(*a*) It was possible to determine the temperature of transition, as previously defined, with as few as seven test specimens (S14-70K).

(*b*) A rather wide spread is to be observed in the notch-sensitivity characteristics, as evidenced by the range in transition temperatures for steels of the same class and thickness, depending upon variations in composition, mill practice, grain size, etc.

Table 2—Chemical and Physical Properties of Medium Steels

CODE	THICKNESS	CONDITION	PROCESS	C (%)	Mn (%)	P (%)	S (%)	Si (%)	N (%)	Y.S. (p.s.i.)	T.S. (p.s.i)	Elong. in 8"-(%)
A	3/4"	AS ROLLED	SEMI-KILLED	.25	.49	.011	.045	.04	.004	34090	58640	33.4
B	3/4"	AS ROLLED	SEMI-KILLED	.16	.76	.011	.030	.05	.005	31850	56980	33.5
C	3/4"	AS ROLLED	SEMI-KILLED	.25	.51	.014	.035	.047	.009	35500	65240	30.3
D	3/4"@1/2"	AS ROLLED	FULLY KILLED	.19	.55	.013	.030	.25	.005	40500	67200	27.0
E	3/4"@1/2"	AS ROLLED	RIMMED	.23	.37	.017	.020	.004	.004	30950	58430	30.6
H	3/4"	AS ROLLED	FULLY KILLED	.17	.78	.012	.030	.16	.005	35000	62550	29.8
CX	3/4"	AS ROLLED	RIMMED	.14	.47	.006	.035	.01	.004	36830	57320	33.0
CY	3/4"	AS ROLLED	RIMMED	.18	.34	.012	.045	.01	.004	37340	61440	26.0
CZ	3/4"	AS ROLLED	RIMMED	.16	.40	.00	.040	.01	.004	35550	57310	30.0
W	3/4"	AS ROLLED	FULLY KILLED	.21	.52	.013	.010	.23	.0049	37230	62540	30.3
S14-70 K	3/4"	AS ROLLED	SEMI-KILLED	.14	.70	.009	.035	.08	.005	31780	58720	32.4
S19-62 K	3/4"	AS ROLLED	SEMI-KILLED	.19	.62	.008	.020	.07	.005	31400	58000	32.8
S 20-62 F	3/4"	AS ROLLED	SEMI-KILLED	.20	.62	.008	.020	.07	.005	31500	57700	31.8
S18-93 K	3/4"	AS ROLLED	SEMI-KILLED	.23	.93	.019	.030	.09	.005	36630	66000	29.5
S18-93 F	3/4"	AS ROLLED	SEMI-KILLED	.18	.93	.014	.035	.10	.004	36300	65100	30.8

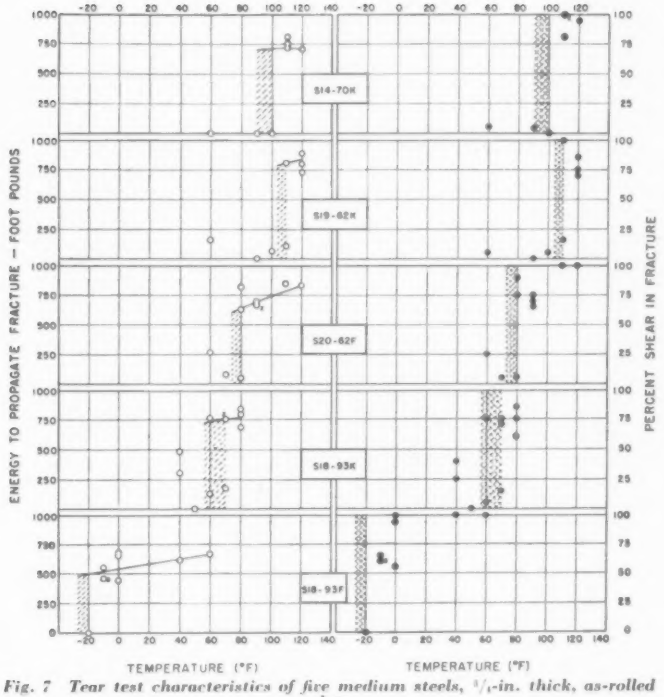

Fig. 7 Tear test characteristics of five medium steels, 3/4-in. thick, as-rolled plate

(*c*) The tabulation shows no direct correlation between manganese content or manganese-to-carbon ratio and notch sensitivity and that a manganese content of 0.60 to 0.90% or a manganese-to-carbon ratio of over three will not necessarily insure a low transition temperature.

(*d*) It is to be added that in connection with the "S" steels, items 2 and 4 are from one heat while items 5 and 8 are from another; a fine grain size was effected in the instance of items 4 and 8 by aluminum treatment contributing apparently to a downward shift of the start of transition from 110 to 80° F. in the case of the former and from 70 to −20° F. in the case of the latter.

Table 3—Chemical and Physical Properties of High-Tensile Steels

CODE	THICKNESS	CONDITION	C (%)	Mn (%)	P (%)	S (%)	Si (%)	V (%)	Ti (%)	Y.P. (p.s.i.)	T.S. (p.s.i.)	Elong. in 8" (%)
A1	7/8"	AS ROLLED	.19	1.24	.016	.040	.30	.05	.010	60100	85300	20.0
A2	1"	AS ROLLED	.20	1.26	.015	.040	.31	.05	.009	55300	81200	22.0
A3	1 1/4"	AS ROLLED	.18	1.23	.014	.035	.35	.05	.011	51400	79100	24.3
A4	1 1/8"	AS ROLLED	.18	1.23	.013	.040	.31	.05	.012	50200	79000	24.3
A9	1 1/4"	AS ROLLED	.19	1.19	.020	.045	.30	.05	.011	55500	77300	25.0
A10	1 1/8"	AS ROLLED	.20	1.19	.024	.020	.28	.05	.010	52500	81800	25.0

Fully Killed Steels

The three fully killed steels (D, H, W) investigated showed a range in carbon from 0.17 to 0.21%, manganese from 0.52 to 0.78%, yield from 35,000 to 40,500 psi. and tensile strength from 62,540 to 67,200 psi. Complete tear test properties of project steels D and H were reported in a previous paper.[2] Tear test properties of Steel W are shown in Fig. 8. It is to be observed by reference to Table 1 and Fig. 8 that steels Dr, W and H show transition temperatures of 60, 60 and 50° F., respectively, and Steel D in the normalized condition (Dn) showed transition at 70° F.

APPLICATION OF NAVY TEAR TEST TO EVALUATION OF NOTCH SENSITIVITY OF "VANITY-TYPE" HIGH-TENSILE STRUCTURAL STEELS

In an effort to gather data on the notch-sensitivity characteristics of "vanity-type" high-tensile structural steel plate, sample plate material representing current mill production under Navy contracts is being made available to the laboratory with which the authors are associated for the determination of tear test properties. Six steels have been investigated to date, the chemical and physical properties of which are given in Table 3.

Representative load-extension diagrams obtained on high-tensile steel specimens tested at temperatures

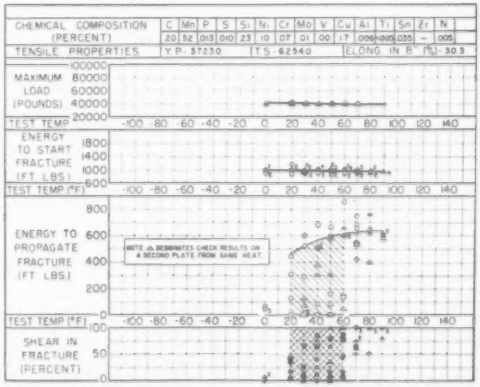
CHEMICAL COMPOSITION (PERCENT)
C .20 Mn .52 P .013 S .010 Si .23 Ni .10 Cr .07 Mo .01 V .00 Cu .17 Al .006-.025 Ti .035 Sn – Zr .005 N
TENSILE PROPERTIES
Y.P.-37230 T.S.-62540 ELONG. IN 8" (%)-30.3
MAXIMUM LOAD (POUNDS)
TEST TEMP
ENERGY TO START FRACTURE (FT. LBS.)
TEST TEMP (°F)
ENERGY TO PROPAGATE FRACTURE (FT. LBS.)
NOTE: Δ DESIGNATES CHECK RESULTS ON A SECOND PLATE FROM SAME HEAT
TEST TEMP (°F)
SHEAR IN FRACTURE (PERCENT)

Fig. 8 Tear test properties of Steel W, fully killed, as-rolled, 3/4-in. plate

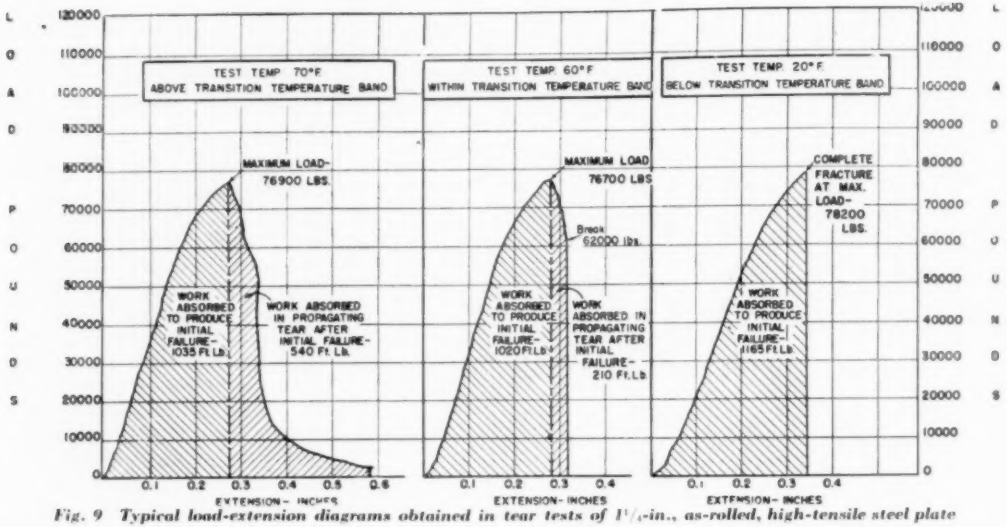
TEST TEMP 70°F
ABOVE TRANSITION TEMPERATURE BAND
MAXIMUM LOAD-
76900 LBS.
WORK ABSORBED TO PRODUCE INITIAL FAILURE- 1035 Ft. Lb.
WORK ABSORBED IN PROPAGATING TEAR AFTER INITIAL FAILURE- 540 Ft. Lb.
TEST TEMP 60°F
WITHIN TRANSITION TEMPERATURE BAND
MAXIMUM LOAD
76700 LBS
Break
62000 lbs.
WORK ABSORBED TO PRODUCE INITIAL FAILURE- 1020 Ft.Lb
WORK ABSORBED IN PROPAGATING TEAR AFTER INITIAL FAILURE- 210 Ft.Lb
TEST TEMP 20°F
BELOW TRANSITION TEMPERATURE BAND
COMPLETE FRACTURE AT MAX. LOAD- 78200 LBS.
WORK ABSORBED TO PRODUCE INITIAL FAILURE- 1165 Ft.Lb
LOAD
POUNDS
EXTENSION- INCHES

Fig. 9 Typical load-extension diagrams obtained in tear tests of 1 1/4-in., as-rolled, high-tensile steel plate

above, within and below the transition temperature region are shown in Fig. 9. Complete tear test properties for a 7/8-in. thick, as-rolled, high-tensile steel are shown in Fig. 10, as an example of the behavior of this class of steel. Representative fractures of specimens tested at temperatures above, within and below transition are shown in the right-hand portion of Fig. 11. Beneath each fracture are shown the energy required to propagate the fracture and the percentage of shear in the fracture. A graphical summary of the tear test characteristics of the six high-tensile steels is presented in Fig. 12. The transition temperature for the 7/8-in. plate is 50° F.; for the 1 in., 40° F; and for the 1 1/4-in. plates from 70 to 15° F.

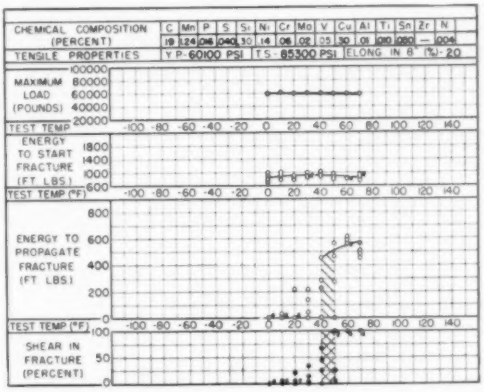
CHEMICAL COMPOSITION (PERCENT)
C Mn P S Si Ni Cr Mo V Cu Al Ti Sn Zr N
.19 1.24 .016 .040 .30 .14 .06 .02 .05 .30 .01 .020 .080 — .004
TENSILE PROPERTIES
Y.P- 60100 PSI T.S- 85300 PSI ELONG IN 8" (%)- 20
MAXIMUM LOAD (POUNDS)
TEST TEMP
ENERGY TO START FRACTURE (FT LBS)
TEST TEMP (°F)
ENERGY TO PROPAGATE FRACTURE (FT LBS)
TEST TEMP (°F)
SHEAR IN FRACTURE (PERCENT)

Fig. 10 Tear test properties of high-tensile steel plate, 7/8 in. thick (35.7 lb.), as-rolled

APPLICATION OF NAVY TEAR TEST TO EVALUATION OF NOTCH SENSITIVITY OF HIGH-YIELD STRENGTH (75,000 PSI. MIN.) STRUCTURAL STEELS

As part of a broad program which is aimed at the development of a high-strength weldable structural steel, the authors investigated six alloy steels in thicknesses of 3/4 and 1 in. which were treated for a minimum yield strength of 75,000 psi. The composition, condition and tensile properties of these steels are given in Table 4.

Representative load-extension diagrams obtained on high-yield steel specimens tested at temperatures above, within and below the transition temperature region are shown in Fig. 13. Complete tear test properties for steels 1 and 4 are shown in Figs. 14 and 15, respectively, as examples of the behavior of this

Table 4—Chemical and Physical Properties of High-Yield (75,000 Psi. Min.) Steels

CODE	THICKNESS & CONDITION		C (%)	Mn (%)	P (%)	S (%)	Si (%)	Ni (%)	Cr (%)	Mo (%)	V (%)	Ti (%)	Cu (%)	Y.S. (p.s.i.)	T.S. (p.s.i.)	Elong. in 8"-(%)
1	3/4"	N	.17	1.45	.016	.015	.28	.18	.09	.38	—	—	.05	73700	97600	24.5
2*	3/4"	Q&D	.17	.82	.022	.040	.75	.14	.60	.16	.012	<.005	.11	73700	96400	15.0
	1"	Q&D	.19	.82	.021	.035	.75	.14	.60	.16	.012	<.005	.11	85250	101200	13.5
3	3/4"	Q&D	.18	1.43	.019	.031	.20	.61	.05	.43	.08	<.01	.08	85/90000		
	1"	Q&D	.22	1.39	.021	.027	.20	.55	.046	.45	.075	<.005	.045	85/90000		
4	1"	Q&D	.16	1.25	.020	.018	.24	.08	.054	.15	.003	.023	.12	84660	96280	23.5
5	3/4"	Q&D	.17	.25	.012	.016	.16	2.30	1.53	.19	.01	<.005	.02	84570	99800	26.3
	1"	Q&D	.19	.26	.012	.016	.16	2.64	1.47	.19	.01	<.005	.02	80060	98350	26.2
6	1"	N&D	.14	.46	.011	.016	.15	2.23	.03	.34	.09	—	.64	75000 Min.		

* STEEL 2 – .04 Zr

class of steel. Representative fractures of specimens tested at temperatures above, within and below transition are shown in the left-hand portion of Fig. 11. A graphical summary of the tear test characteristics of the six steels is presented in Fig. 16. It is to be observed that:

(*a*) In connection with steels 3 and 5 in $^3/_4$ in. thickness, tear tests performed at temperatures of

Fig. 11 Typical tear test fractures of high-yield and high-tensile steels at temperatures above, within and below transition

-110 and $-100°$ F., respectively, developed full shear fractures indicating that start of transition is below these temperatures. It was not practicable with the equipment at hand to conduct tests at temperatures much below $-100°$ F.

(*b*) In marked contrast to steels 3 and 5, it is to be observed that steels 1 and 2 in $^3/_4$ in. thickness show transition temperatures of $+60$ and $+20°$ F., respectively.

(*c*) Steels 2, 6, 4, 5 and 3 in 1 in. thickness, listed in order of decreasing transition temperatures, show values of $+50$, $+20$, -50, -90 and $-95°$ F., respectively.

(*d*) In the instance of steels 2, 3, and 5, available in both thicknesses, a change from $^3/_4$ to 1 in. thickness resulted in an upward shift in the transition temperature.

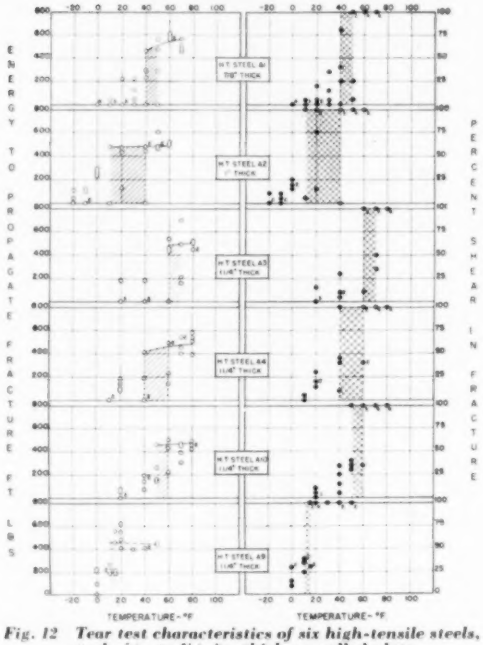

Fig. 12 Tear test characteristics of six high-tensile steels, steels, $^7/_{16}$- to $1^1/_4$-in. thick, as-rolled plate

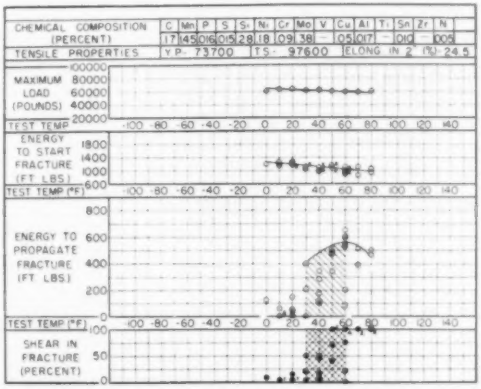

Fig. 14 Tear test properties of a Mn-Mo steel, normalized, high yield, $^3/_4$-in. plate thickness. (Steel Code 1 of Table 4)

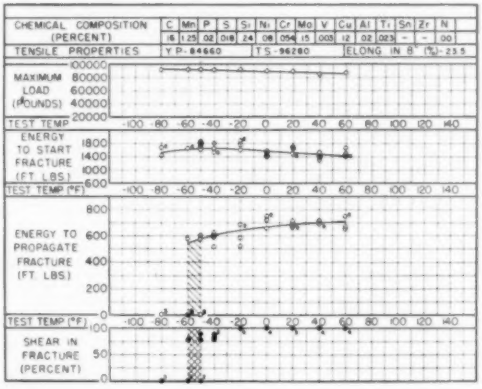

Fig. 15 Tear test properties of a Mn-Mo steel, quenched and drawn, high-yield, 1-in. plate thickness. (Steel Code 4 of Table 4)

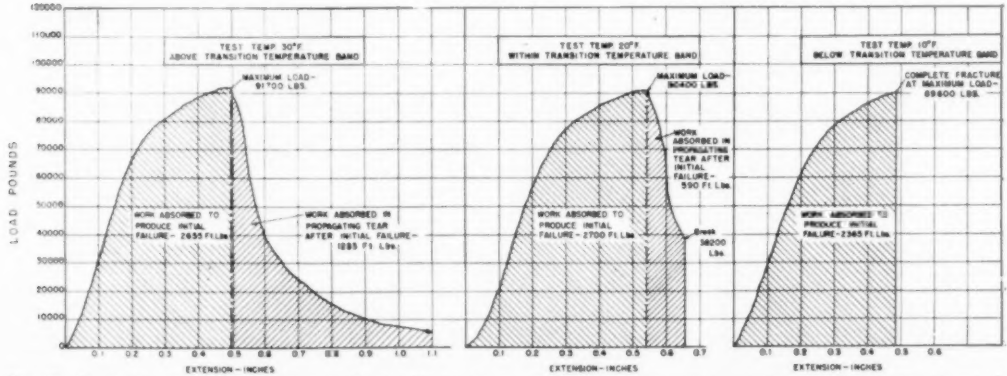
TEST TEMP 30°F ABOVE TRANSITION TEMPERATURE BAND
MAXIMUM LOAD-91700 LBS.
WORK ABSORBED TO PRODUCE INITIAL FAILURE-2655 Ft Lbs
WORK ABSORBED IN PROPAGATING TEAR AFTER INITIAL FAILURE-1285 Ft Lbs
TEST TEMP 20°F WITHIN TRANSITION TEMPERATURE BAND
MAXIMUM LOAD-80400 LBS.
WORK ABSORBED IN PROPAGATING TEAR AFTER INITIAL FAILURE-590 Ft Lbs
WORK ABSORBED TO PRODUCE INITIAL FAILURE-2700 Ft Lbs
Break 38200 Lbs.
TEST TEMP 10°F BELOW TRANSITION TEMPERATURE BAND
COMPLETE FRACTURE AT MAXIMUM LOAD-89400 LBS.
WORK ABSORBED TO PRODUCE INITIAL FAILURE-2365 Ft Lbs
LOAD POUNDS
EXTENSION-INCHES
EXTENSION-INCHES
EXTENSION-INCHES

Fig. 13 Typical load-extension diagrams obtained in tear tests of 1-in. quenched and drawn, high-yield (75,000 psi. min.), steel plate

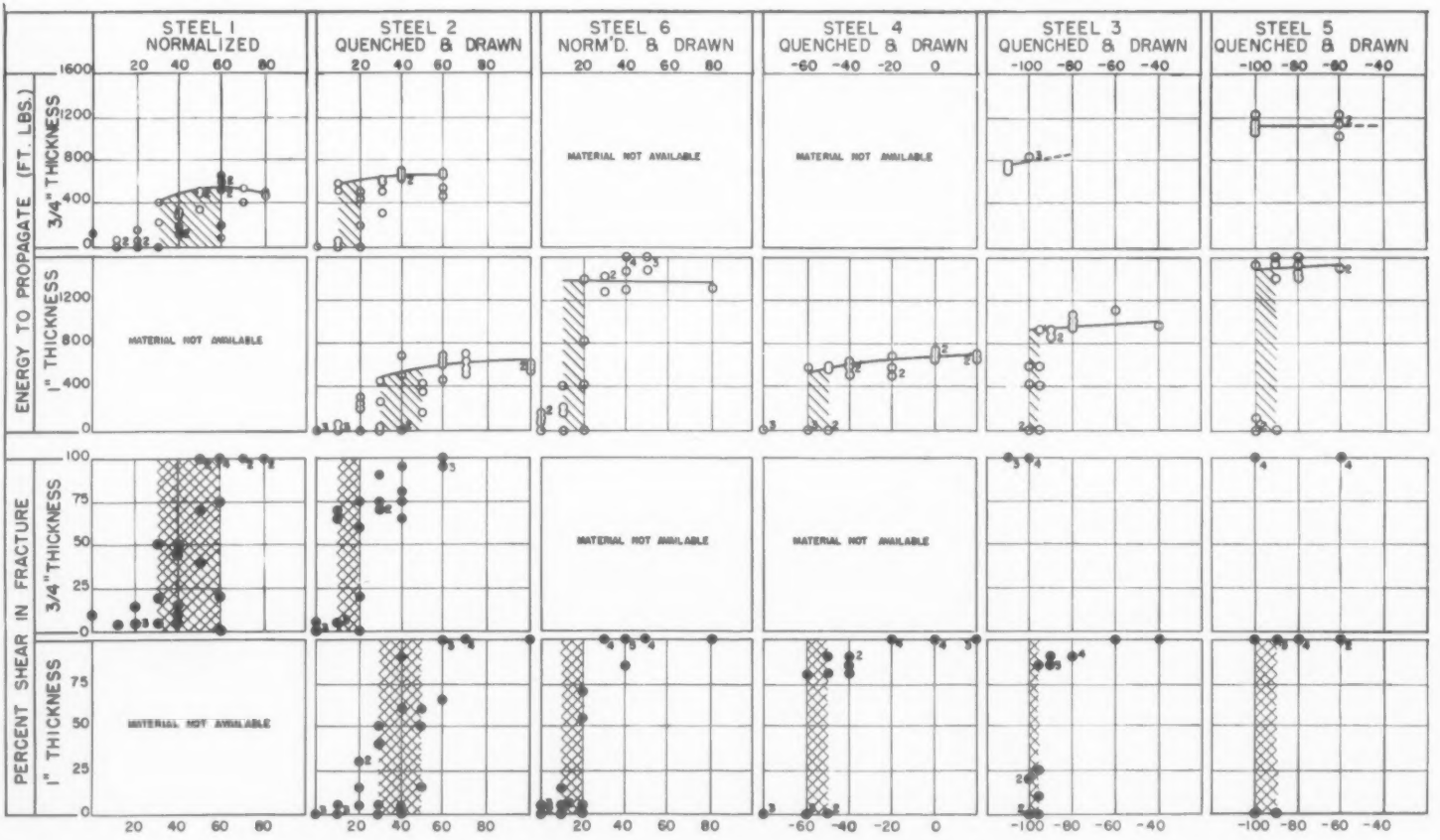

Fig. 16 Tear tests characteristics of six high-yield (75,000 psi. min.) steels, 3/4- and 1-in. thick plate, heat treated

(*e*) A marked difference in transition temperature is evident for steels 1 and 4, the former being a ¾-in. plate containing 0.17% carbon, 1.45% manganese and 0.38% molybdenum and showing a transition temperature of +60° F. in a normalized condition, while the latter is a 1-in. plate containing 0.16% carbon, 1.25% manganese and 0.15% molybdenum and showing a transition temperature of −50° F. in a quenched and drawn condition.

STUDY OF GEOMETRY OF NAVY TEAR TEST SPECIMEN

The authors are currently engaged in the study of the geometry of the tear test specimen with a view of determining the effect of the following variables:*

(*a*) Notch acuity in the present design is defined by the 0.039-in. radius provided by the No. 47 drill and all of the work reported herewith was based on the keyhole-type notch. A study is being made of the effect of notches of higher and lesser acuity than the present notch in connection with medium and high-yield steels. Some work in connection with the use of a keyhole vs. a jeweler's saw-cut notch on two medium steels was included in previous papers[1, 2] by the authors. The increase in notch constraint from a 0.039-in. radius to a 0.010-in. wide JSC notch resulted in no marked change in the location of transition but tended to narrow the width of the transition region.

(*b*) Eccentricity of loading in the present design is defined by the 0.039-in. distance from the base of the notch to the line of application of initial loading. No tests have as yet been made to investigate the effect of eccentricity but some work is contemplated in the direction of increasing eccentricity, upon completion of the study of notch acuity.

(*c*) Fracture length in the present design is defined by the 1.961-in. distance beneath the base of the notch. A small amount of preliminary work in decreasing this length has indicated no significant shift in transition but the maximum load required to fracture the specimen was proportionately reduced.

(*d*) Specimen thickness is defined by the as-rolled plate thickness which is considered as one of the advantages of the tear test method as compared with other methods which do not provide for testing in full plate thickness. It is considered important to determine the transition characteristics of a given steel as affected by a change in the as-rolled thickness and when tested in the full plate thickness. Changes in the transition characteristics, as affected by plate thickness, would be due to,

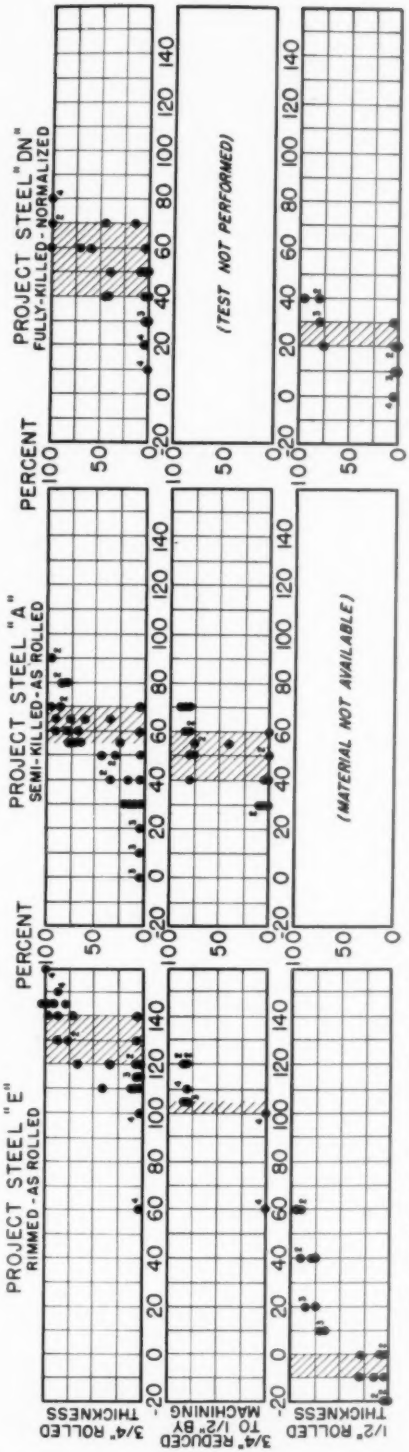

Fig. 17 Tear test characteristics of project steels E, A and DN as affected by reduction in plate thickness based on per cent shear in fracture

* For an extensive treatment of this subject, the reader is referred to a paper by A. B. Bagsar.[3]

on one hand, a change in the degree of constraint and, on the other hand, to a change in metallurgical characteristics of the material, both factors tending generally to raise the transition temperature for an increase in the as-rolled plate thickness.

Some data on the tear test characteristics of medium steel, as affected by specimen thickness, are presented in Fig. 17 in which are shown values of per cent shear in fracture vs. test temperature, as influenced by (1) reduction in specimen thickness from an as-rolled thickness of $^3/_4$ to $^1/_2$ in. by machining an equal amount off each plate surface for project steels E and A, and (2) variation in the as-rolled thickness from $^3/_4$ to $^1/_2$ in. for steels E and Dn. The graph indicates that:

(*a*) The effect of reduction in specimen thickness is to shift the transition to a region of lower temperature.

(*b*) The shift is greater when the reduction in thickness is accomplished by rolling than when it is accomplished by machining.

(*c*) The shift is greater for rimmed Steel E than for semikilled Steel A or fully killed Steel Dn.

(*d*) The marked difference in the transition temperatures of steels E and Dn in $^3/_4$-in. rolled thickness is no longer evident in the same steels rolled to $^1/_2$-in. thickness.

In connection with high-tensile steels, Fig. 12 shows some preliminary data on the effect of as-rolled thickness on the location of transition. Steels A1 to A4 were from different slabs of one heat while steels A10 and A9 were from different slabs of another heat; both heats were from the same mill. It is to be observed that the variation in transition caused by changes in as-rolled thickness of steels A1 to A4 from $^7/_8$ to $1^1/_4$ in. is less pronounced than that exhibited by steels A10 and A9 which were rolled to the same thickness from different slabs of the same heat.

In connection with the high-yield steels which were tested in $^3/_4$ and 1 in. thicknesses (Fig. 16), a shift in transition for steels 2, 3, and 5 to a region of lower temperature is evident for a change in thickness from 1 to $^3/_4$ in.

EFFECT OF NITROGEN

It may be observed from Table 2 that the most significant variation in the chemistry of steels A and C, which showed a marked difference in transition characteristics under all tests except the Charpy, is in the nitrogen content, Steel C with the higher transition temperature showing a nitrogen content of 0.009% as compared to Steel A with 0.004%. In an effort to determine the significance of nitrogen content and its relation to the transition characteristics of medium steel, nitrogen determinations were made of thirty $^1/_2$-in. medium steel plate samples representing different mill practices which had previously been investigated for keyhole Charpy transition characteristics. In addition, triplicate tear

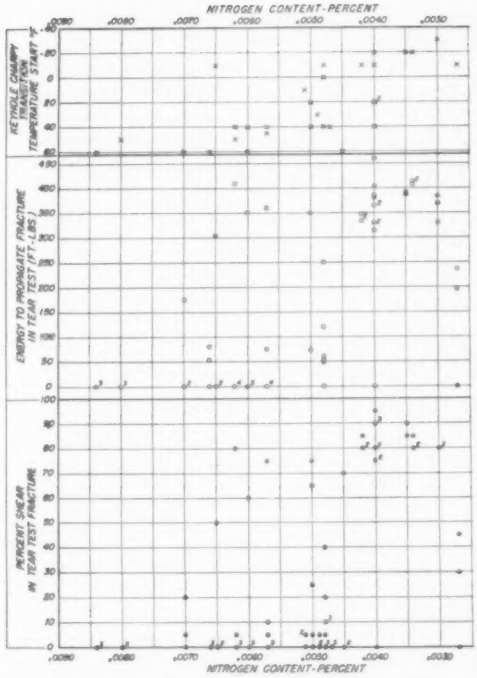

Fig. 18 Effect of nitrogen content on keyhole Charpy, transition temperature and tear test characteristics at 40° F. of thirty $^1/_2$-in. thick, medium ship plate steels

tests were conducted on each of these steels at a selected temperature of 40° F. In Fig. 18 are plotted (*a*) keyhole Charpy transition temperatures, (*b*) energy-to-propagate fracture in tear tests and (*c*) percentage of shear in tear test fractures vs. nitrogen content. With the exception of a few out of line points, the graphs suggest that higher transition temperatures and increased susceptibility to cleavage fracture are associated with a nitrogen content of 0.005% and over.

APPLICATION TO QUALITY CONTROL OF SHIP PLATE

As previously concluded,[1, 2, 6] all existing specifications for ship plate are not sufficiently selective to exclude steel which is notch sensitive at operating temperatures. A review of current specifications for ship plate reveals the startling fact that notch-sensitivity characteristics have not been given due consideration inasmuch as no requirement is contained which would discriminate between steels that tend to fracture in a shear-type mode and steels that tend to fracture in a cleavage-type mode under service conditions. The epidemic of brittle ship failures during the last war brought to light the need for improvements in ship design and workmanship and also focused attention on the necessity for the augmentation of existing ship plate specifications for the purpose of safeguarding against potential

brittle structural failures. This paper has been prepared with the objective of contributing further to the existing background and for the purpose of stimulating action toward the improvement of specifications for ship plate along the line of incorporating a test requirement capable of discriminating against steels which would tend to fail in a brittle mode under ship service conditions. The authors have previously suggested[2] that the tear test method could be utilized for quality control purposes by conducting the test at a single temperature once such test temperature has been established on the basis of large-scale or simulated service tests. The basis of acceptance for such tests would be that all specimens tested at the selected temperature show a predominantly shear or ductile-type fracture originating from the root of the notch and extending to at least half of the entire fracture area.

A step in the direction of augmenting an existing specification for medium ship plate is observed in a recent revision of Section 39, "Materials for Hull Construction and Equipment" of the American Bureau of Shipping Rules.[7] This revision provides for the introduction of chemical composition requirements and stipulates in part that plates over 1/2 in. and up to 1 in., inclusive, in thickness (Class B) shall contain carbon 0.23% maximum and manganese 0.60 to 0.90%, and that plates over 1 in. in thickness (Class C) shall contain carbon 0.25% maximum, manganese 0.60 to 0.90% and silicon 0.15 to 0.30% and, in addition, be made with fine grain practice. None of the above requirements are applicable to plates up to and inclusive of 1/2 in. in thickness (Class A).

The exclusion of rimmed steels in thicknesses over 1/2 in. is considered capable of effecting positive improvement in the quality of ship plate from the standpoint of susceptibility to brittle failure inasmuch as all rimmed steels tested by the authors in 1/2-in. thickness indicated satisfactory performance under notch-sensitivity tests, while all rimmed steels tested in 3/4-in. thickness indicated tear test transitions above the temperature level which the authors consider satisfactory for ship plate. It will be noted from Fig. 6 that 3/4-in. rimmed steels E, CX, CY and CZ showed transition temperatures of 80° to 140° F. A 1 1/4-in. thick rimmed steel plate tested at Lehigh University[8] under sponsorship of the Pressure Vessel Research Committee of the Welding Research Council showed a tear test transition temperature of 150° F. The same steel rolled to and tested in 5/8-in. thickness showed a transition of 60° F., which compares favorably with the data in Fig. 17 which indicates a suppression in transition temperature for Steel E from 140° F. for 3/4-in. thickness to 0° F. for the 1/2-in. as-rolled thickness.

The requirement that plate thicknesses over 1 in. be of fully killed steel made by a fine-grain practice is considered to be a step in the right direction although the authors have had no direct experience to date with fully killed steels in thicknesses over 1 in. A fully killed steel tested at Lehigh University[8] in thicknesses of 5/8 and 1 1/4 in. showed tear test transition temperatures on the basis of energy absorption of 57° and 60° F., respectively. It is reasonable to assume that improved notch-sensitivity characteristics may be derived from a fully killed, fine-grain practice.

It is the authors' impression that the range of thickness covered by Class B of A.B.S. rules, namely, over 1/2 to and inclusive of 1 in., represents the bulk of plate material used in ship structures of the type which played an important role in the epidemic of brittle failures during World War II. The only measure contained in the revision applicable to this range of thickness which is designed to safeguard against susceptibility to brittle failure under ship service conditions is the requirement that the steel be of a manganese content of 0.60 to 0.90% and which by inference would exclude rimmed steel. In the authors' experience, this measure will not effectively eliminate steels of poor notch-sensitivity characteristics and may eliminate steels of satisfactory quality. While the requirement would eliminate project steel C with a transition temperature of 135° F. because of a manganese content of 0.51%, it would also eliminate project Steel A, project Steel D and Steel W with transition temperatures of 70° F. and below because of manganese contents below 0.60%. The requirement would not eliminate steels S19-62K and S14-70K with manganese contents within the specified range but with relatively high transition temperatures of 110 and 100° F., respectively. The measure involves an additional consumption of ferro-manganese without positive assurance that the notch-sensitivity characteristics of the steel produced will invariably be of an acceptable level.

CONCLUSIONS

It has been confirmed on the basis of the investigation of additional steels that the Navy tear test method is capable of sharply defining the transition temperature of ship plate and related structural steels using either the energy to propagate tearing or the percentage of shear in the fracture as the basis for evaluation of the change from ductile to brittle-type failure. The two bases of evaluation indicate the same transition temperature.

The tear test method reveals, in a marked manner, differences in the behavior of such steels with respect to their relative susceptibility to cleavage fracture.

The authors are strongly of the opinion that until such time as we have a broader understanding of notch sensitivity and how it is influenced by specific variables in mill practice and chemistry of the steel, we must, by necessity, depend on an actual test performance designed to discriminate between steels with respect to their relative susceptibility to cleavage fracture. In this connection, the authors consider the tear test method as worthy of consideration for quality control of ship plate and related steels inasmuch as:

(*a*) It is economical in regard to material, time and cost of preparation and testing.

(*b*) It utilizes a test specimen which is simple in design and readily reproducible.

(*c*) The plate is tested in full thickness and the specimen includes an adequate fracture area for visual evaluation of the fracture type.

(*d*) The evaluation may be made by a visual estimation of the percentage of shear in the fracture without the need for making energy measurements.

(*e*) The testing procedure is simple. For quality control purposes, it may prove to be sufficient to conduct the test at a single predetermined temperature, the acceptance prerequisite being that all specimens tested at the selected temperature show a predominantly shear mode of fracture.

ACKNOWLEDGMENT

The authors desire to express their appreciation to the Bureau of Ships of the Navy Department and the Ship Structure Committee for continuing this program, providing contact with other collaborating activities and permission to publish this paper. They are grateful to Captain D. C. Redgrave, USN, Director of the Material Laboratory, New York Naval Shipyard, for his encouragement and review of the paper. Thanks are also due to A. Chick and J. J. Gabriel, associates of the authors, for assistance rendered in obtaining the test data.

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Discussion by Wendell P. Roop

Added emphasis should be given to the conclusion of the authors which they state as follows: "Until we have a broader understanding of notch sensitivity and how it is influenced by specific variables in mill practice and chemistry of the steel, we must depend on an actual test performance designed to discriminate between steels with respect to their relative susceptibility to cleavage fracture."

It is my own opinion that it is dangerous to depend on any specification of the process of steel production and that such a practice can be defended only as a makeshift pending the development of an acceptable acceptance test.

Wendell P. Roop is connected with Swarthmore College.

Discussion by David Arnott

As the new ship steel specification of the American Bureau of Shipping has been mentioned in the discussion a few remarks with regard to the development of these requirements might be of some interest. Some ten years ago in a paper read before the Society of Naval Architects and Marine Engineers I ventured the opinion that the time had come for a complete revision of existing structural steel specifications. This proposal was prompted by the fact that numerous plate failures were being experienced in our Shipyards during the process of construction of welded ships and in the knowledge of the complete failures of a brittle nature which had occurred to some new welded bridges in Europe and which had been attributed in part to indifferent welding but mainly to the particular material, that is, Thomas steel used in their construction. Even at that time it was becoming recognized that the ordinary structural steel which had proved quite satisfactory in the past for riveted structures was not the most suitable that could be obtained commercially for structures which were to be welded. The advent of the war and the abnormal demand for steel precluded the development of new specifications for the time being. However, one step taken by the American Bureau was to tentatively reduce the tensile limits from a range of 60,000 to 72,000 psi. to 58,000 to 70,000 psi. after being assured by the steel manufacturers that this slight modification would in itself tend to reduce the number of plate failures occurring in the course of construction of welded ships. It should be emphasized that this step was taken before the large emergency shipbuilding program had been started. That the welded ships built prior to the advent of the war, which were mostly of the smaller sizes, had been practically immune from structural troubles in service, did not blind us to the fact that trouble might be experienced with welded ships of the larger sizes if only in view of the heavier plating involved in their construction and the relatively higher stresses to which they were subjected in service. As you are all aware structural troubles did develop with our warbuilt welded vessels which I am free to admit were much more serious than had been anticipated, the first major failure being the tanker *Schenectady* which broke in two while lying in smooth water at the Builder's dock. The Committee appointed by the American Bureau to investigate this unprecedented failure found that while the steel material was up to specification in that it satis-

David Arnott is a retired Vice-President and Chief Surveyor of the American Bureau of Shipping, now retained as a consultant. He is a Past President of the American Welding Society.

The paper by Noah A. Kahn and Emil A. Imbembo appears in this issue.

factorily met the ordinary commercial tests it was low in impact values when subjected to Charpy tests.

The War Metallurgy Committee under the auspices of the Board to Investigate the Design and Methods of Construction of Welded Steel Merchant Vessels, appointed by the Secretary of the Navy, went into the steel question exhaustively and developed the importance of notch sensitivity as a primary factor in the brittle fractures which were characteristic of welded ship failures, the majority of which had occurred in service under cold weather conditions. In short, it became apparent that if we were to continue to build large welded structures a tougher steel than had been available in the past would be eminently desirable, that is, a steel that was not unduly notch sensitive at the minimum temperature likely to be met with under service conditions. Investigations carried out with a number of project steels had shown conclusively that notch toughness could be improved by the use of a steel of relatively lower carbon, higher manganese content and that without sacrifice of other desirable qualities. Very considerable work has been carried out within the last few years with a view to developing an acceptance test which will readily evaluate the property of notch toughness and one of the proposals in this connection is the tear test described in Messrs. Kahn and Imbembo's excellent paper.

About a year ago the A.B.S. decided that the time had come to take definite action in the matter and submitted certain proposals for a revised Ship Steel Specification to a Special Committee on which the Steel Manufacturers were adequately represented. The steel company technicians were very helpful and cooperative and after several meetings unanimous agreement was reached on the new specification which is published in the 1948 American Bureau Rules. No special acceptance test for notch sensitivity was embodied in the specification which, however, does provide for a lower carbon limit and a range for manganese content in the "B" and "C" grades. The inclusion of any chemical requirements whatever is entirely novel to ship classification steel specifications.

One of the discussers of this paper has inferred that the A.B.S. new specification is of little value in the absence of any acceptance test for notch sensitivity. The fact is that to have required Charpy tests would have resulted in a substantial increase in cost over and above the extras already required for the thicker grades of steel under the new specification. Again, many important large welded tankers were on the point of being placed and the A.B.S., which has a moral responsibility for the structural efficiency of the ships classed with the Society felt that the new specification should be issued immediately without waiting for the development of a commercial acceptance test which would be satisfactory to all of the various interests, both scientific and practical, who were studying this problem. It is not considered that the new steel specification is the last word on the subject. The A.B.S. will continue their investigations and from time to time will make check tests of the new steel as delivered to the Shipyards. I may say that such check tests as already have been made show that we are getting what can properly be regarded as an improved steel and that the new A.B.S. steel specification is a step in the right direction. The authors are to be congratulated on presenting a very informative paper.

Authors' Reply

The authors are grateful to Mr. Arnott for his discussion, since he has been associated with shipbuilding for many years. They are in full agreement with him on the premise that "if we were to continue to build large welded structures, a tougher steel than what had been available in the past would be eminently desirable, that is, a steel that was not unduly notch sensitive at the minimum temperature likely to be met with under service conditions."

We are somewhat in disagreement with him as to what constitutes a "cure" for an undesirable condition whose existence is presently admitted by all. Mr. Arnott sincerely believes that notch-toughness is improved by the use of steel of relatively lower carbon and higher manganese content and that the investigations carried out on a number of the project steels had conclusively confirmed this. The authors fail to find any definite confirmation in the studies of the project steels to the effect that a manganese content of 0.60 to 0.90% coupled with a correspondingly lower carbon content will conclusively establish that the steel will not be unduly notch-sensitive under service conditions.

Relative notch-sensitivity characteristics of the project steels are shown in Table 1 of the paper. Steels B and A with manganese-to-carbon ratios of 4.7 and 2.0 show transition temperatures of 60 and 70° F., respectively. Similarly, steels H and Dr with manganese-to-carbon ratios of 4.6 and 2.9 show transitions of 50 and 60° F., respectively.

The lowering of the transition temperature by 10° F. cannot be interpreted as conclusive evidence of the improvement to be derived from higher carbon-to-manganese ratios.

The case for a higher carbon-to-manganese ratio and its effect on brittle fracture of mild steel is stated by Barr and Honeyman.* They prepared four high-frequency 18-lb. casts which were subsequently forged to $1^{3}/_{4}$-in. squares, cropped and then rolled to $^{5}/_{8}$-in. square bars. The four heats varied in carbon and manganese contents as follows:

C, %	*Mn*, %	*Mn/C*
0.19	0.27	1.42
0.17	0.68	4.0
0.115	0.89	7.7
0.10	1.19	11.9

* W. Barr and A. J. K. Honeyman, "Effect of the Manganese/Carbon Ratio on the Brittle Fracture of Mild Steel," *Journal of Iron and Steel Institute*, **157**, Part 2, October 1947.

(*Continued on page 177-s*)

Transition Temperatures of Structural Steels

—effects of geometry and welding on high yield strength steels

Under restrained conditions fracture of welded specimens occurs below the yield strength of the steel. Small specimens predict the behavior of the steel in the large specimens. Some electrodes produce weldments less susceptible to cracking under plastic deformation

by A. Boodberg and E. R. Parker

THE paper describes the various tests that were conducted at the University of California on high yield strength structural steels. The work was a part of a large program, sponsored by the United States Navy, on the behavior of various steels used in ship construction. The primary objective of the tests was to study the effect of variations of steel composition on their transition temperature by means of tests of notched plates and welded structural assemblies.

Three types of specimens were used, two simple notched specimens and one that provided restraint to plastic flow at a corner produced by welding together steel plates set along three mutually perpendicular planes. The specimens were tested in tension at various temperatures in order to determine the temperature for a particular steel and specimen at which the mode of fracture of the specimen changed from ductile to brittle type. Auxiliary tests were conducted by using a simple bend test to determine the effect of welding on the behavior of the high yield strength structural steels.

Results of the tests show that the four high yield strength structural steels used in this investigation, when tested in the form of restrained welded specimens, have transition temperatures that vary from −65° F. for one of the steels, to as high as +75° F. for one of the others tested. The tests of notched specimens invariably showed transition temperatures for a particular steel that were approximately 50° F. lower than those indicated by tests of the large specimens. However, it was found that the steels are rated in the proper order of their brittleness by all three of the tests.

The stress at the maximum load, during the tests of small notched specimens, invariably exceeded the ultimate strength (as determined by standard tensile bar tests) of the particular steel. However, during the tests of the restrained welded specimens, the fracture occurred at nominal stress values that were below the yield strength of the steel.

The auxiliary bend tests of small welded specimens of high strength steel indicated that only two types of mineral-coated electrodes, of the many that were tested, would produce weldments that were not susceptible to cracking during the early stages of plastic deformation.

INTRODUCTION

The results reported in this paper constitute a part of a large research program sponsored by the Bureau of Ships of the United States Navy and coordinated by the Committee on Ship Contruction of the National Research Council. This investigation was concerned with the behavior of various types of high yield strength structural steels that were tested in the form of notched plates and welded structural assemblies. Testing temperatures ranged from +100° F. down to −150° F. Previously conducted investigations,[1–4] which were a part of the same program, have been primarily concerned with the behavior of various types of mild steels under conditions similar to those reported in the following pages.

Four low-alloy high-strength structural steels were tested during the course of the program, all of them having a yield strength in the neighborhood of 70,000 psi., and tensile strengths of approximately 100,000 psi. All steels were tested in the quenched and drawn condition.

In order to make possible the comparison of results obtained with the high yield strength structural steels and those obtained from the mild steels, some addi-

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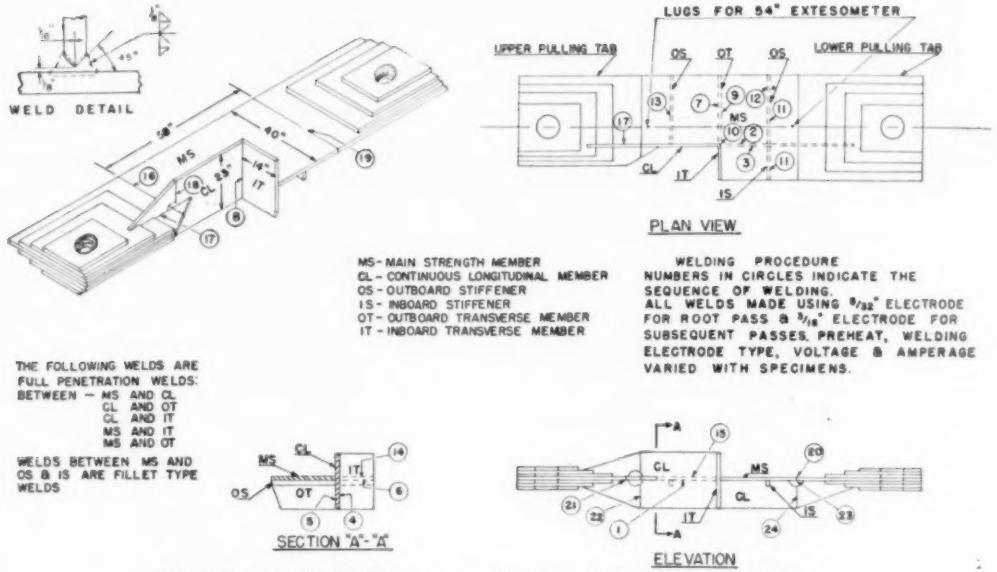
WELD DETAIL
LUGS FOR 54" EXTESOMETER
UPPER PULLING TAB
LOWER PULLING TAB
OS
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CL
IT
IS
PLAN VIEW
MS - MAIN STRENGTH MEMBER
CL - CONTINUOUS LONGITUDINAL MEMBER
OS - OUTBOARD STIFFENER
IS - INBOARD STIFFENER
OT - OUTBOARD TRANSVERSE MEMBER
IT - INBOARD TRANSVERSE MEMBER
WELDING PROCEDURE
NUMBERS IN CIRCLES INDICATE THE SEQUENCE OF WELDING.
ALL WELDS MADE USING 5/32" ELECTRODE FOR ROOT PASS & 3/16" ELECTRODE FOR SUBSEQUENT PASSES. PREHEAT, WELDING ELECTRODE TYPE, VOLTAGE & AMPERAGE VARIED WITH SPECIMENS.
THE FOLLOWING WELDS ARE FULL PENETRATION WELDS:
BETWEEN -- MS AND CL
CL AND OT
CL AND IT
MS AND IT
MS AND OT
WELDS BETWEEN MS AND OS & IS ARE FILLET TYPE WELDS
SECTION "A"-"A"
ELEVATION

Fig. 1 Restrained welded specimen used for tests of high-tensile strength steels

tional tests on specimens of one of the mild steels were conducted.

The primary objective of the investigation was to determine the effects of variations in steel composition on the temperature at which the type of fracture changed from the ductile shear type to the generally brittle cleavage type. The specimen used for these tests contained a discontinuity produced by welding together four plates on three mutually perpendicular planes to form a right angle corner.

The two minor objectives of the investigation were: (1) to determine the influence of temperature on the mode of fracture of notched flat tensile specimens of the various steels, and (2) to determine the effect of temperature on the brittle behavior of weldments that were made by welding the high yield strength structural steels with commercially available electrodes at various temperatures of preheat.

The physical properties and chemical compositions of the various steels used in this investigation are given in Table 1. The manufacturer's data for weld deposit properties are shown in Table 2.

EXPERIMENTAL WORK

Test Program

The main feature of the investigation consisted of tension tests at various temperatures on specimens containing abrupt changes in section produced by welding together four pieces of $^3/_4$-in. thick plate as shown in Fig. 1. These specimens, made of high yield strength

Table 1—Properties and Compositions of High Yield Strength Structural Steels Used in the Investigation

Steel No.:	*1*	*2*	*3*	*4*	*B**
Type:	*Low alloy*	*Low alloy*	*Low alloy*	*Low alloy*	*Mild*
Heat treatment:	*Quenched and drawn*	*Quenched and drawn*	*Quenched and drawn*	*Quenched and drawn*	*Semikilled, as-rolled*
Physical properties					
Yield strength, psi., av.	66,000	80,000	80,000	84,000	36,000
Ultimate strength, psi., av.	89,000	97,000	100,000	100,000	60,000
Elongation % in 2 in. av.	26	22	20	23	26
Reduction in area, %, av.	64	60	60	68	63
Approximate Chemical Composition					
Carbon	0.19	0.14	0.16	0.16	0.15
Manganese	1.08	0.75	1.45	0.27	0.77
Silicon	0.24	0.77	0.21	0.17	0.05
Molybdenum	0.42	0.16	0.48	0.20	...
Chromium	...	0.60	...	1.13	...
Zirconium	...	0.09	...	...	...
Phosphorus	0.014	0.023	0.017	0.014	0.010
Sulphur	0.023	0.028	0.038	0.021	0.029
Vanadium	...	...	0.08	...	...
Nickel	...	...	0.53	2.32	...

* Mild Steel Br properties included for comparison.

structural steel, have been called "restrained welded specimens." They were similar in construction to, but considerably smaller in size than, the previously tested "hatch corner specimens,"[1] that were made of $^3/_4$-in. thick mild steel. The high yield strength structural steels had to be tested in this reduced scale form in order that the capacity of the testing machine would not be exceeded, because the strength of the steels used in this investigation (see Table 1) was almost twice as great as that of the mild steels previously used. The restrained welded specimen was selected for test because it incorporated restraint to plastic flow in a welded specimen having an extremely severe type of structural design.

In order to establish a basis for comparison between the many published results obtained on the behavior of the mild steels[1-3] and those obtained in the present program on the behavior of the high yield strength structural steels, it was considered desirable to conduct tests on the restrained welded specimens made from one of the mild steels previously used. The configuration and the loading axis for the restrained welded specimen used in this investigation were so chosen that the stress distribution in the main strength member would be similar to that found in the deck member of the "hatch corner" specimen.[1] Results, obtained from the elaborate strain gage installations at and near the corners of several of the restrained welded specimens, confirmed that the stress distributions during the tension tests were almost identical to the ones found in "hatch corner" specimens and were not affected by the type of steel used or by change of specimen size.

Tension tests were made on 12-in. wide centrally notched specimens and 3-in. wide edge notched specimens of the four high yield strength structural steels and of the one mild steel. For each steel and for each type of specimen the tensile strength, energy to maximum load and to failure, and the per cent of the fracture surface which failed by shear, were determined at various temperatures. From these data it was possible to determine the temperature at which the mode of fracture changed from shear to cleavage.

In order to obtain some idea of the weldability of the various steels, and to check the behavior of weldments, small specimens were welded with the commercially available electrodes enumerated in Table 2, and then were subjected to a bend test at different temperatures. These specimens were $^3/_4$-in. thick, 6-in. wide and 9-in. long. They contained various types of longitudinal welds at the center lines of the plates and the welds in most cases were ground flush with the surface of the plate prior to the test; no artificial notches were added. These specimens were tested in a special jig, the specimens being loaded so that the direction of maximum stress was parallel to the weld. The low temperature tests were conducted by immersing the jig containing the specimen in a bath of alcohol which was maintained at the desired testing temperature to within $\pm 2°$ F. during the test. Various degrees of preheat temperature were tried in the welding of the different steels.

Test Procedure

The large restrained specimens, of the design shown in Fig. 1, were tested in tension at several temperatures in order to establish the temperature vs. energy absorbed relationship for each steel. Manganin wire extensometers[2] were used on all specimens to measure the over-all elongation of the specimens at various loads. From the load strain curves thus obtained it was possible to determine the energy absorbed by the specimen during the test. Both energy to maximum load and energy to fracture were recorded. Specimens were loaded until fracture occurred in the main strength member as well as in the continuous longitudinal member. The specimens were maintained within $\pm 5°$ F. of the testing temperature by circulating cold air through an insulated plywood box which surrounded the specimen. Those specimens which were tested at the extremely low temperatures required additional cooling. This was provided by spraying liquid nitrogen into the box enclosing the specimen, with the nitrogen spray so adjusted that it was uniformly distributed throughout the volume of the box. After the temperature was brought down to below that desired, the nitrogen supply was shut off, allowing the specimen to warm up slowly to the desired test temperature. A large number of thermocouples was used to check the distribution of temperature in the specimen, particularly in

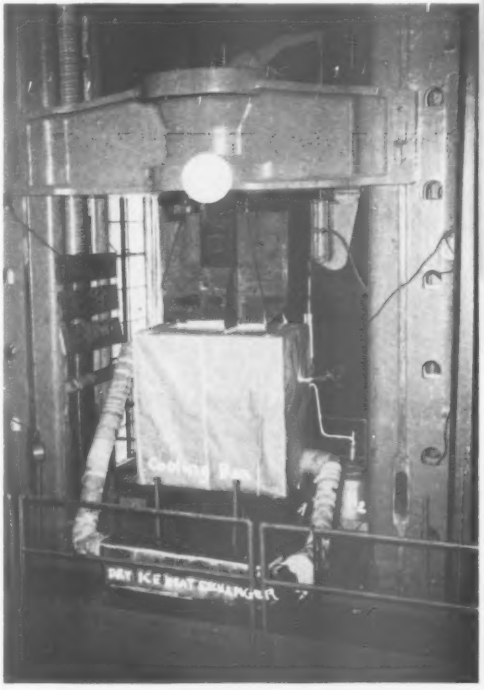


Fig. 2 Restrained welded specimen ready for test
Showing cooling box, dry ice heat exchanger and nitrogen bottle

the critical region through which the fracture would pass. Maximum variations in temperature that were observed were ±5° F. at points approximately 20 in. below and above the corner. Except for the very low temperature tests, windows were provided in the box so that the formation and progress of cracks could be followed visually. A specimen under test in the 3,000,000-lb. machine with the cooling box in place is shown in Fig. 2.

Two types of notched tensile specimens were also tested, one which was a 12-in. wide centrally notched plate, shown in Fig. 3 (*a*), and a 3-in. wide edge notched specimen shown in Fig. 3 (*b*). The 12-in. wide specimens were flame cut from large plates and had a $^{3}/_{4}$-in. hole drilled in the center, from which 1-in. long hacksaw cuts were made, extending from the edges of the hole toward the edges of the specimen. This notch was further extended for an additional $^{1}/_{8}$ in. toward each edge of the plate with a 0.010-in. thick jeweler's saw. The 3-in. wide specimens were flame cut from a large plate and $^{1}/_{2}$-in. deep notches were made inward from each edge at mid-length of the specimen with a 0.042-in. thick hacksaw blade. These two types of specimens were tested at various temperatures and the tensile strength, energy absorbed to maximum load and to failure, and the per cent of fracture surface which failed by shear were recorded. From these data it was possible to determine a transition temperature for each type of specimen and each steel tested.

Specimens for the bend tests were made by butt welding two 3-in. wide by 9-in. long pieces of steel, as shown in Fig. 3 (*c*), with various types of commercially available electrodes and using various temperatures of preheat. Some specimens were made by depositing a weld bead on the surface of 6- by 9- by $^{3}/_{4}$-in. plates. Since these specimens were small it was necessary to maintain careful control of the specimen temperature during welding. In a few cases it was found necessary to allow the specimen to cool to the proper preheat temperature before continuing with the welding. The bend test specimens were tested at +70° F. and at −40° F. in the jig shown in Fig. 3 (*d*). The angle at which the first sign of failure appeared was noted and the load and energy absorbed were recorded. The bend angle was measured by the relative movement of the jig members and checked after removal of the specimen from the fixture. The results of this test were used as a preliminary criterion for estimating the performances of the large structural specimens and also for evaluating electrodes and determining the desirable preheat temperatures.

Welding Procedure

All of the restrained specimens used in this investigation were welded according to the sequence and type of weld shown in Fig. 1. For the first seven specimens tested, made of high-strength structural steel, Type 310 electrodes were used with 300° F. preheat (±25° F.). Specimens subsequent to No. 7-S were made with Electrode A and 175° F. preheat (±25° F.). Currents and voltages used were those recommended by the manufacturers of the electrodes, and each batch of electrodes was carefully heated for at least 1 hr. at 600° F. prior to use, to insure freedom from moisture. All specimens were welded by the same team of welders, and the critical areas around the corner were carefully examined by means of magnaflux; X-rays were taken of several of the specimens. With one or two exceptions a period of from 24 to 48 hr. was allowed to elapse between the completion of the welding and the actual test.

RESULTS

General

The primary objective of these tests was to rate the several high yield strength structural steels according to their relative transition temperatures. The transition temperature may be defined as a temperature at which the mode of fracture changes from the ductile shear type to the brittle cleavage type. If a sufficiently large number of specimens were tested (as in the case of the 3-in. wide edge notched specimen tests) this temperature may be established very closely. However, as the expense of testing a large number of specimens of the restrained welded type is prohibitive, in this investigation it was necessary to approximate the transition temperature of a particular steel by arbitrarily choosing a point halfway between the two test temperatures—one that resulted in a predominately shear fracture of the test specimen and the other that gave a predominately clea-

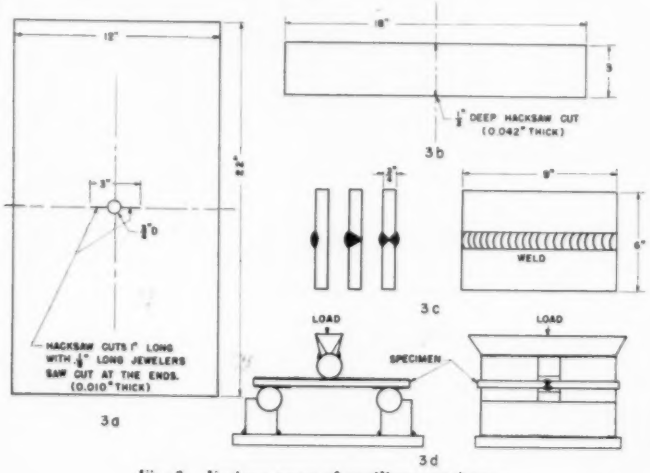


Fig. 3. Various types of auxiliary specimens

vage fracture. Thus, the transition temperature for a steel, as determined by the large restrained welded specimens, may be in error by as much as ±20° F., because in some cases temperature differentials between test points were quite large.

The transition temperatures for the steels, when tested by means of 3-in. wide edge notched specimens, were established to within ±5° F., as a large number of tests could be conducted rapidly and inexpensively.

The high yield strength structural steels could not be welded with cellulose-coated electrodes because of the occurrence of underbead cracking; consequently, it was necessary to make rather extensive tests on various commercially available electrodes having mineral-type coatings. Among these electrodes were included the 25 chromium-20 nickel stainless steel electrodes, Type 310. During the early part of the investigation the Type 310 electrodes produced bend test specimens which were much more ductile and thus less susceptible to cracking during the early stages of plastic deformation than any of the ferritic-type of mineral-coated electrodes which were available at that time. Consequently, two of the steels which were first investigated were welded with Type 310 electrodes, using 300° F. preheat. Subsequently a ferritic-type electrode, Electrode A, was obtained which compared favorably in ductility with Type 310 electrode, and in addition had considerably higher yield and tensile strengths than did the Type 310. For this reason the Electrode A, using a 175 to 200° F., preheat temperature, was

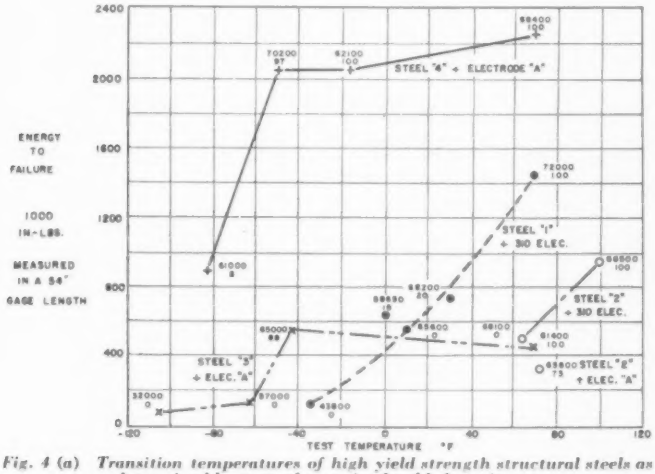

ENERGY TO FAILURE
1000 IN-LBS.
MEASURED IN A 54" GAGE LENGTH
TEST TEMPERATURE °F
STEEL "4" + ELECTRODE "A"
STEEL "1" + 310 ELEC.
STEEL "2" + 310 ELEC.
STEEL "3" + ELEC. "A"
STEEL "2" + ELEC. "A"

Fig. 4 (a) Transition temperatures of high yield strength structural steels as determined by tests of restrained welded specimens

Numbers adjacent to test points indicate nominal stress at maximum load and type of failure in per cent shear

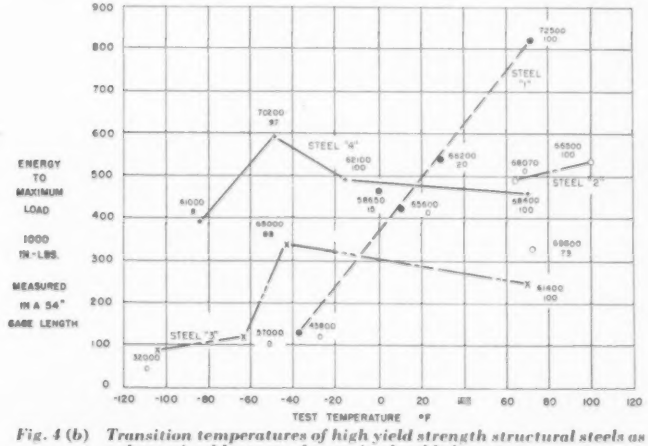


Fig. 4 (b) Transition temperatures of high yield strength structural steels as determined by tests of restrained welded specimens

Numbers adjacent to test points indicate nominal stress at maximum load and type failure in per cent shear

Fig. 5 Typical example of failure of a restrained welded specimen showing the origin of fracture

Table 2—Average Values Shown for the Various Electrodes Used in the Investigation

Manufacturer's data on weld deposits								
Electrode code letter:	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*310*
Classification:	*Low alloy*	*Low alloy*	*A.W.S. E6020 (As-welded)*		*Low alloy*	*A.W.S. E6015*	*Low alloy*	*U.S.N. 46E4*
Physical properties								
Tensile strength, psi.	95,000	110,000	98,000	78,000	96,000	72,000	112,000	80,000
Yield strength, psi.	77,000	95,000	85,000	59,000	85,000	60,000	92,000	
Elongation in 2 in., %	25	15	20	21	9	32	17	35
Chemical analysis, %								
Carbon	0.08	0.15	0.12	0.07	0.15	0.08	0.16	...
Manganese	1.5	1.8	1.8	0.53	1.7	0.55	1.9	...
Silicon	0.25	0.25	0.25	0.06	0.3	0.25	...	...
Sulphur, max, %	0.03	0.03	0.04	0.02	0.01	0.02	0.03	...
Phosphorus, max. %	0.03	0.03	0.04	0.02	0.01	0.02	0.03	...
Molybdenum	0.35	0.4	0.35	0.82	0.35	...	0.33	...
Chromium	...	...	...	...	...	...	...	25
Nickel	...	...	...	...	...	...	...	20

employed for welding all remaining restrained welded specimens.

Restrained Welded Specimens

Five structural type specimens of Steel 1 were welded with the stainless steel electrodes and 300° F. preheat. These specimens were tested in tension at temperatures ranging from −35 to +70° F. in order to establish the transition temperature for the steel for this type of specimen. The results are shown in Figs. 4 (*a*) and 4 (*b*), along with similar transition temperature curves for the other four steels tested, and are tabulated in Table 3.

The transition temperature for Steel 1 in the form of the restrained welded specimen was about +40° F. compared with a transition temperature of about +5° F. for the 12-in. wide plates, and −10° F. for the 3-in. wide edge notched specimens. The shift in transition temperatures toward higher values for larger, more complicated specimens is a normal behavior and is a tendency which was exhibited by all the mild steels tested previously. However, the values of the maximum nominal stresses at failure for the welded specimens of Steel 1 decreased as the testing temperatures were lowered. This is contrary to the behavior of the other high yield strength structural steels and the mild steel B, the ultimate strengths of which remained approximately the same regardless of the testing temperatures.

Two specimens of Steel 2 were welded with Type 310 electrodes and 300° F. preheat. The one tested at +63° F. failed with cleavage type fracture and had a relatively low energy absorption, 496,000 in.-lb. and a maximum stress of 68,000 psi. The other specimen was tested at +100° F. and failed by shear in a ductile manner. The energy absorption for the specimen was 940,000 in.-lb. and a maximum stress of 66,500 psi. An additional specimen of Steel 2 was subsequently welded with the ferritic electrodes, Electrode A, using a preheat temperature of 300° F. This specimen was tested at +73° F. and failed by a mixed shear and cleavage fracture, having an energy absorption of 326,000 in.-lb., and a maximum stress of 65,600 psi. The use of widely different welding electrodes does not appear to alter the behavior of this steel and thus the apparent transition temperature for Steel 2, as determined by means of restrained welded specimens, is in the neighborhood of +75° F. The transition temperatures determined by means of notched specimens for Steel 2 were

Table 3—Principal Results of Restrained Welded Specimens Tested

Specimen No.	*Steel*	*Test temp., ° F.*	*Max. stress, psi.*	*Energy*		*Type fracture in % shear*
				To max. load	*To failure*	
1-S	1	+70	72,456	811,000	1,426,000	100
2-S	1	−35	43,860	117,200	117,200	0
3-S	1	0	58,596	470,000	606,600	15
4-S	1	+11	65,614	427,000	568,000	0
5-S	1	+30	66,210	524,000	725,000	20
6-S	2	+63	68,070	496,000	496,000	0
7-S	2	+100	66,500	530,000	940,000	100
8-S	2	+73	65,600	326,000	326,000	73
9-S	4	+72	68,400	462,000	2,256,000	100
10-S	4	−18	62,100	490,000	2,040,000	100
11-S	4	−48	70,200	598,000	2,040,000	97
12-S	3	+70	61,400	240,000	426,000	100
13-S	4	−83	61,000	390,000	900,000	8
14-S	3	−108	32,000	90,000	90,000	0
15-S	3	−44	65,000	338,000	540,000	88
16-S	3	−62	57,000	126,000	126,000	0

Load carrying area for specimens is 28.5 ± 0.5 sq. in.
Gage length for energy measurements is 54 in.
Specimens 1-S through 7-S welded with Type 310 electrodes.
Specimens 8-S through 16-S welded with ferritic electrode "A".

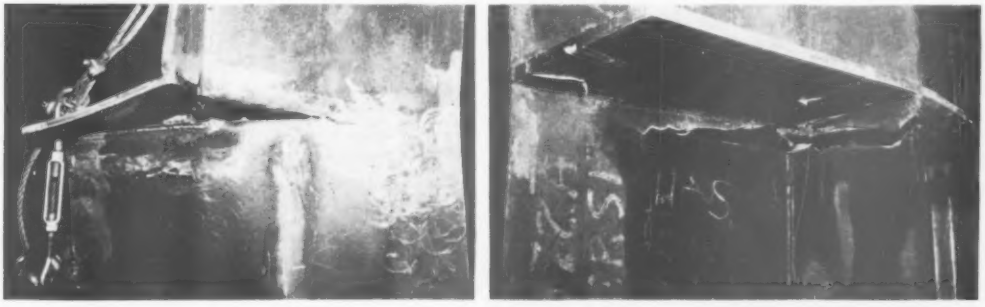
about +20° F. These high transition temperatures were unexpected as it was believed that this steel would perform satisfactorily because of its chemical composition and good impact strength as determined by Charpy tests. The apparent 55° F. difference in transition temperature between that determined by small notched specimens and the one obtained by tests of restrained welded specimens was similar to that of Steel 1 and the Mild Steel B.

Four specimens of Steel 3 were tested in the restrained welded form at temperatures ranging from −108 to +70° F. The transition temperature for this steel in this large structural type specimen was approximately −50° F. The 12-in. wide centrally notched plates and the 3-in. wide edge notched specimens were also tested over a wide range of temperatures and the transition temperature was found to be about −95° F. for the 12-in. wide plate and −102° F. for the 3-in. wide specimen. With this steel, as with steels 1 and 2, the difference in transition temperature between the small notched specimens and the restrained welded specimens was approximately 50° F.

Steel 4 was tested in the restrained welded specimen form at temperatures ranging from −83 to +72° F. The transition temperature for the large welded specimen was in the neighborhood of −65° F., compared with the transition temperature of about −108° F. for the 3-in. wide edge notched specimens and −102° F. for the 12-in. wide centrally notched plates. The difference in transition temperature of about 40° F. is not as great as that for the other high yield strength structural steels. This smaller difference in transition temperature may be significant in view of the fact that Steel 4 also exhibited an energy absorption ability that was by far greater than that shown by any of the other steels that were tested.

For the purpose of comparison, Mild Steel B, in the as-rolled condition and designated in previous reports[2] as Br, was tested in the restrained welded specimen form at temperatures ranging from +2 to +72° F. These specimens were welded with E6020 type electrode using no preheat. The transition temperature

Fig. 6 Restrained welded specimen in testing machine
Showing pulling tabs and Manganin wire extensometer



Front Back

Fig. 7 Specimen 11-S shear type failure

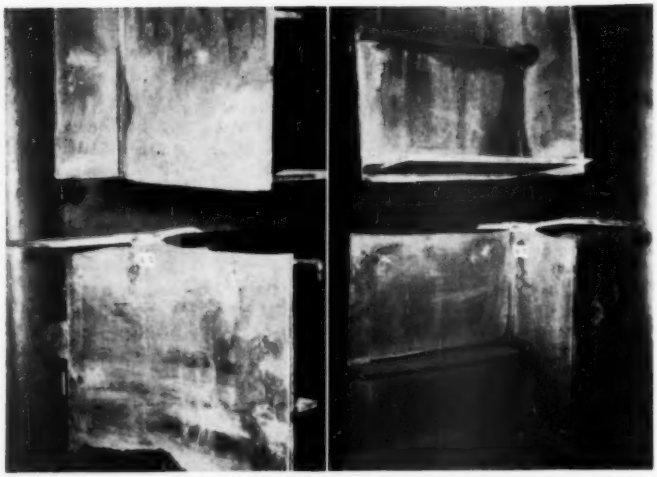


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Fig. 8 Specimen 16-S cleavage type failure

for this steel was approximately +58° F., compared with a transition temperature of +15 and +20° F. for the 12-in. wide centrally notched plates and the 3-in. wide edge notched specimens. The difference in transition temperatures, as determined by notched and restrained specimens, was approximately 40° F. for this mild steel, a value similar to that shown by the high yield strength structural steels tested. Thus it seems that geometry of the specimen is responsible for a shift of the transition temperature to a higher value as the size and restraint of the specimen are increased.

All of the restrained welded specimens failed in a manner similar to the fracture in the large "hatch corner" type of specimens of mild steel. All fractures originated at the square corner in the region of the intersecting welds, between the main stress member *MS*, shown in Fig. 5, the inboard transverse member *IT*, and the continuous longitudinal member *CL*. The fracture usually progressed outboard in the main strength member with the failure of the continuous longitudinal member beginning shortly after the origin of the fracture in the main strength member. Figure 6 shows one of the high yield strength specimens assembled in the 3,000,000-lb. tensile testing machine. Typical examples of the fractured surfaces of the high yield strength structural specimens are shown in Figs. 7 and 8.

During the early tests a great deal of difficulty was encountered in fracturing the specimen because the corner formed by the pulling tabs, the continuous longitudinal and the main strength member acted as a more severe discontinuity than the corner of the specimen itself. This resulted in premature failure near the welded joint of the pulling tab and the specimen. Because of this difficulty, some of the earlier specimens had to be reloaded a number of times; for example, Specimen 3-S was tested four times before failure occurred in the welded corner. This retesting may have influenced the results of the energy absorption of this specimen. These premature failures were remedied by redesigning the pulling tabs and inserting a triangular plate near the joint of the end tab and the specimen.

Notched Specimens

Notched specimens were made from the four lots of high yield strength steel and from the Mild Steel B which was used in an earlier investigation.[2] The transition temperatures, at which the type of fracture changed from the ductile or shear type to that of the cleavage type, were determined for each steel by means

Table 4—Approximate Transition Temperatures of High Yield Strength Structural Steels Determined by Means of Different Specimens

	Temp., °F.				
Steels:	*1*	*2*	*3*	*4*	*B*
Type of Specimen					
3-in. edge notched	−10	+18	−102	−108	+20
12-in. centrally notched	+5	+20	−95	−102	+18
Restrained welded specimen	+40	+75	−50	−65	+58

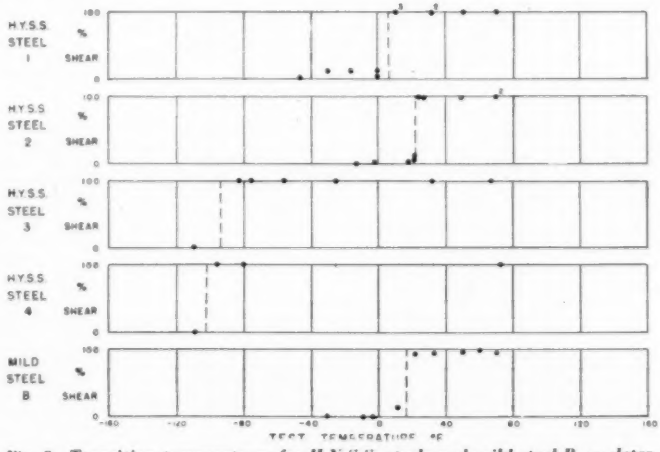

Fig. 9 Transition temperatures for H.Y.S.S. steels and mild steel B, as determined by 12-in. centrally notched specimens

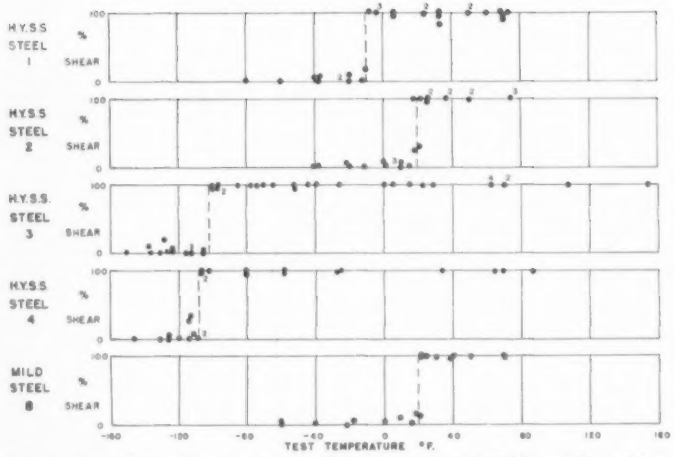

Fig. 10 Transition temperatures for H.Y.S.S. steels and mild steel B, as determined by tests of 3-in. edge notched specimens

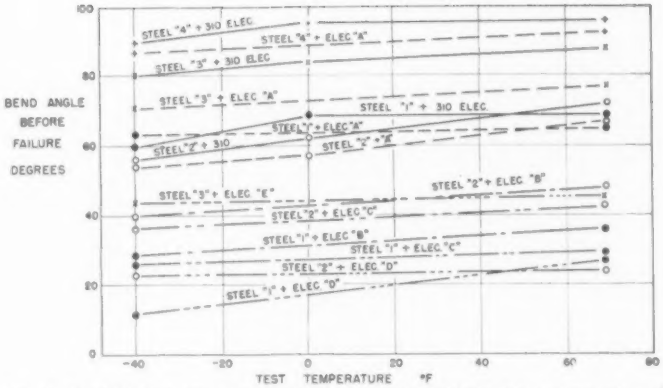
BEND ANGLE BEFORE FAILURE DEGREES
STEEL "4" + 310 ELEC
STEEL "4" + ELEC "A"
STEEL "3" + 310 ELEC
STEEL "3" + ELEC "A"
STEEL "1" + 310 ELEC
STEEL "1" + ELEC "A"
STEEL "2" + 310
STEEL "2" + "A"
STEEL "3" + ELEC "E"
STEEL "2" + ELEC "B"
STEEL "2" + ELEC "C"
STEEL "1" + ELEC "B"
STEEL "1" + ELEC "C"
STEEL "2" + ELEC "D"
STEEL "1" + ELEC "D"
TEST TEMPERATURE °F

Fig. 12 Typical bend test results—H.Y.S.S. steels welded with various mineral coated electrodes

No preheat, double vee butt welds ground off flush with surface of plate

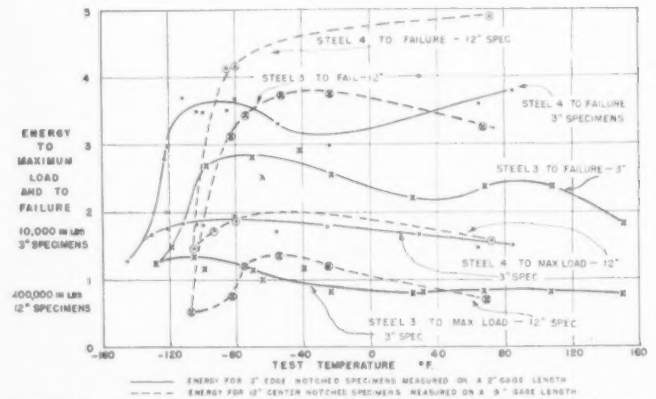
ENERGY TO MAXIMUM LOAD AND TO FAILURE
10,000 in lbs 3" SPECIMENS
400,000 in lbs 12" SPECIMENS
STEEL 4 TO FAILURE – 12" SPEC
STEEL 3 TO FAIL–12"
STEEL 4 TO FAILURE 3" SPECIMENS
STEEL 3 TO FAILURE – 3"
STEEL 4 TO MAX LOAD – 12" 3" SPEC
STEEL 3 TO MAX LOAD – 12" 3" SPEC
TEST TEMPERATURE °F
ENERGY FOR 3" EDGE NOTCHED SPECIMENS MEASURED ON A 2" GAGE LENGTH
ENERGY FOR 12" CENTER NOTCHED SPECIMENS MEASURED ON A 9" GAGE LENGTH

Fig. 11 Energy absorption to maximum load and to failure for notched specimens of H.Y.S.S. steels 3 and 4

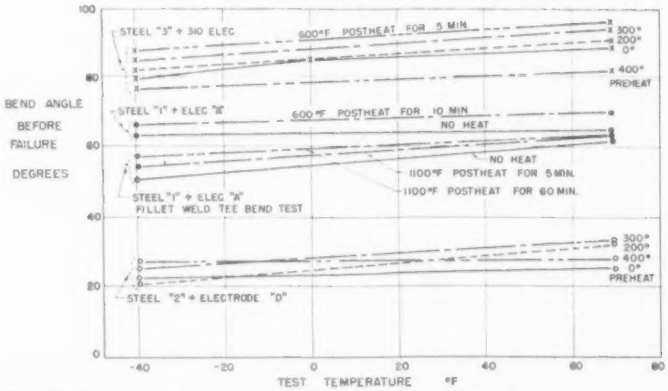
BEND ANGLE BEFORE FAILURE DEGREES
STEEL "3" + 310 ELEC
600°F POSTHEAT FOR 5 MIN
300°
200°
0°
400° PREHEAT
STEEL "1" + ELEC "A"
600°F POSTHEAT FOR 10 MIN
NO HEAT
1100°F POSTHEAT FOR 5 MIN.
1100°F POSTHEAT FOR 60 MIN.
STEEL "1" + ELEC "A" FILLET WELD TEE BEND TEST
STEEL "2" + ELECTRODE "D"
TEST TEMPERATURE °F

Fig. 13 Typical bend test results—H.Y.S.S. steels welded using various preheat and postheat treatments

Double vee butt welds ground off flush with surface of specimen, unless otherwise noted

of tension tests on 12-in. wide centrally notched specimens and 3-in. wide edge notched specimens. The results obtained for the various steels are shown in Figs. 9 and 10. These results show that there is very little difference in transition temperatures as determined by the 12-in. wide centrally notched plates and by the 3-in. wide edge notched specimens; the maximum difference was 15° F. for Steel 1. This steel contained a considerable amount of inclusions and consequently the results were somewhat erratic.

Table 4 shows the approximate transition temperatures for the various steels as determined by tests of the three different specimens. One of the most significant results of this investigation is that all steels are rated in the same order of relative brittleness by the three types of specimens. The transition temperatures determined by tests of large restrained specimens were approximately from 40 to 50° F. higher than the temperatures indicated by small notched specimens, for all of the steels tested. Thus, the approximately 50° F. difference in transition temperatures may be attributed to the geometry and restraint of the larger specimens.

The relative energy absorption to maximum load and to failure of the notched specimens, as shown by Fig. 11, was similar to that of the large restrained specimens.

It is of interest to note that the high yield strength structural steels tested in the form of the 3-in. wide edge notched specimens showed stresses at maximum loads which exceeded the nominal tensile strength, as determined by standard bar tests, by as much as 20%. The maximum tensile stress in the 12-in. wide centrally notched specimens was, however, either equal to or somewhat lower than the tensile strength obtained with standard tensile specimens. In the large restrained welded specimens the fracture invariably occurred at stress values that were below the yield strength of the steel.

Bend Tests

Typical results of the bend tests carried out on the high yield strength structural steels are shown in Figs. 12 and 13. Tests were made at two temperatures only, +70 and −40° F. Specimens failing at +70° F. invariably failed by shear and the cracks were difficult to detect until they had progressed to a somewhat advanced stage. At −40° F., however, the formation of the first tiny crack was almost invariably followed by complete failure of the specimen. The Type 310 electrodes performed in the bend test in a commendable manner and were consequently chosen for the early tests on the restrained welded specimens. Subsequently, ferritic type Electrode A was obtained which also performed exceptionally well and in addition had much more desirable mechanical properties than did the Type 310 electrodes. Therefore, Electrode A was used for all remaining large welded specimens. It was found in the bend tests that there was an optimum preheat temperature for each steel. Specimens welded at this preheat temperature would invariably bend through larger bend angles before fracture would occur. Both above and below this optimum preheat temperature the performance of the welded specimens was poorer.

A few tests were made using the T-Bend test approved by the AMERICAN WELDING SOCIETY in 1945 as a tentative standard. In this test the effect of preheating was found to be parallel to that obtained for the flat plate bend tests. Also a few of the T-Bend specimens welded with Type 310 electrode were post heated to 1100° F. for periods ranging from a few minutes to as long as an hour. This postheat treatment produced a considerable improvement in the ductility of the bend test specimen, but practically all of the beneficial effect was obtained within the first 5 min. of heating.

CONCLUSIONS

1. The restrained welded specimen has provided knowledge of the behavior of high yield strength steels in combination with weld materials, heat-affected zone and a geometric design which restricted plastic flow.

2. Two types of electrodes, both mineral-coated, were found to give satisfactory performances in large welded structures subjected to plastic strain at low temperatures. These were stainless steel Type 310, and Electrode A, which is a ferritic electrode having a high yield and tensile strength and good ductility.

3. The transition temperatures for the four types of high yield strength structural steels tested in the form of large restrained welded specimens ranged from about +75° F. down to approximately −65° F.

4. The transition temperatures as determined by the 3-in. wide edge notched specimens and the 12-in. wide centrally notched specimens were almost the same for a particular steel and ranged from approximately +15 to −108° F. for the four steels tested.

5. The relatively constant difference of approximately 50° F. in transition temperature which was observed in the tests of large restrained specimens, as compared to the transition temperature determined by tests of smaller notched specimens may be attributed to the geometry and restraint of the large specimen.

6. The maximum nominal tensile stresses obtained during the tests of the 3-in. wide edge-notched specimens of a particular steel were invariably greater than the nominal ultimate strength of the steel as determined by tests of standard tensile bars.

7. The maximum nominal tensile stresses for the 12-in. wide center-notched specimens were either equal to or slightly below the nominal ultimate strength of the steel as determined by tests of standard tensile bars.

8. Fractures invariably started and failures occurred in the large restrained specimens at nominal stress values that were below the yield strengths of the steels as determined by the standard tensile tests.

9 Transition temperature is in itself not the only criterion in evaluating the performance of steel for low temperature service. The transition temperatures of Steels 3 and 4 were almost the same, but the energy absorbed by Steel 4 was much greater at any testing temperature than the energy absorbed by Steel 3.

10. It appears that the 3-in. wide edge notched specimens are a cheap and simple means for rating the various steels in their proper order of brittleness.

References

1. DeGarmo, E. Paul, "Tests of Various Designs of Welded Hatch Corners for Ships," THE WELDING JOURNAL, **27** (2), Research Suppl., 50-s to 68-s (1948).

2. Boodberg, A., Davis, H. E., Parker, E. R., and Troxell, G. E., "Causes of Cleavage Fracture in Ship Plate—Tests of Wide Notched Plates," *Ibid.*, **27** (4), Research Suppl., 186-s to 199-s (1948).

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Discussion Paper Notch Sensitivity of Steel Evaluated by Tear Test

(*Continued from page 166-s*)

These were tested for V-notch Charpy transition properties in the annealed and normalized conditions. They conclude that for a given tensile strength, increasing the Mn/C ratio of mild steel lowers the transition range in both the normalized and the annealed conditions and that a practical recommendation would be that for shipbuilding steels, the Mn/C ratio should be not less than 3.0. The authors question the applicability of test results derived from small-scale, high frequency induction melts, rolled and treated (annealed and normalized) in sections of $^5/_8$ in. sq. to what may be expected of large-scale open hearth or duplex heats, rolled to plates of shipbuilding size and used in the as-rolled condition.

The authors' point of view on manganese-to-carbon ratio was stated in the portion of the paper devoted to the "Application of the Tear Test to Quality Control of Ship Plate." It was based on test results derived from full-scale commercial heats, rolled to and tested in $^3/_4$-in. plate thickness (see table included in the discussion of Fig. 7 of the paper). Six semikilled, as-rolled, $^3/_4$-in. thick plate steels with Mn/C ratios of over 3.0 are listed with transition temperatures varying from −20 to +110° F.

The case for higher Mn/C ratios is further weakened by the fact that a group of 13 high-tensile steels (Vanity-type) recently investigated by the authors showed the following relationship between Mn/C ratio and tear test transition temperature:

Plate thickness, in.	*C, %*	*Mn, %*	*Mn/C*	*Transition Temp., ° F.*
$1^1/_4$	0.19	1.27	6.7	−80
$1^1/_4$	0.18	1.27	7.1	+10
$1^1/_4$	0.16	1.26	7.9	+10
$1^1/_4$	0.19	1.18	6.2	+15
1	0.20	1.26	6.3	+40
$1^1/_4$	0.19	1.29	6.8	+40
$1^1/_8$	0.19	1.24	6.5	+50
$1^1/_4$	0.20	1.19	6.0	+50
$1^1/_4$	0.18	1.23	6.8	+60
$1^1/_4$	0.18	1.23	6.8	+70
$1^1/_4$	0.16	1.23	7.7	+80
$1^1/_4$	0.18	1.22	6.8	+80
$1^1/_4$	0.16	1.22	7.7	+90

It is to be noted that associated with Mn/C ratios of 6.0 to 7.9 are tear test transition temperatures varying from −80 to +90° F. (not respectively).

Mr. Arnott states that a substantial increase in the cost of steel plate would have resulted if a notch-sensitivity test, such as the Charpy test, had been incorporated in the new ABS specification. Does Mr. Arnott imply that the cost of making the test would be the factor directly responsible for the substantial increase in cost of the steel? The authors are of the opinion that a simple type of notch-sensitivity test should not in itself greatly increase steel cost. The substantial increase in cost, in their belief, would arise from the fact that the test would undoubtedly reject a certain proportion of the lot under inspection and, because of this circumstance, the producers would necessarily be obliged to raise the price in order to operate without loss.

The authors wish to commend Mr. Arnott on his point of view that the new ABS specifications are not the last word and that the Bureau will continue to investigate the subject and will make check tests of material actually delivered under the new specifications for notch-sensitivity behavior.

Development of Weldable High-Strength Steels

Underbead cracking in steel is caused by release of hydrogen concentrations. Quenched and untempered low-carbon martensite is quite ductile. The influence of composition on underbead cracking and strength is described. Quenched steels give the best results.

by C. E. Sims and H. M. Banta

IN STUDYING the factors which influence and control the response of steel to metal-arc welding, the principles of the conventional brand of metallurgy based on relatively slow heating and cooling rates, or even normal heating followed by liquid quenching, must be modified to suit a "high-speed" type of metallurgy which is geared to the extremely rapid thermal cycles that are actually developed during welding.

In a previous paper, "Metallurgical Factors of Underbead Cracking,"[1] it was shown that the microstructure and thermal history of S.A.E. 4130 steel had a marked influence upon the response of the steel to a rapid heating and cooling cycle as determined by means of a rapid dilatometer test. A good correlation was also found between the dilatometer data and the susceptibility to cold underbead cracking in the heat-affected zone.

The size, type and distribution of the carbides were shown to play an important part in establishing the cold crack sensitivity. The steels with stable or large carbides, which did not go into solution readily during the rapid thermal cycle, and therefore behaved as lower carbon steels when welded, were found to be definitely less susceptible to cold cracking in the heat-affected zone. It was also found that, with the exception of extremely high and low hardness, there was no correlation between hardness in the heat-affected zone and the tendency toward underbead cracking.

In the above paper, the origin of underbead cracks was explained on the basis of very high local aerostatic stresses developed by the sudden release of hydrogen during the low-temperature transformation of small areas of residual austenite where hydrogen remained in solution after the initial transformation of the greater portion of the heat-affected zone. This theory indicates that thermal stresses and restraint in the weld are not the primary causes of underbead cracks but are responsible only for their propagation.

Following the studies of the aircraft steel, work was undertaken on underbead weld cracking in high-tensile carbon-manganese killed plate steel (approximately 0.15/0.20% carbon and 1.15/1.35% manganese and small additions of vanadium or titanium or both). The welding tests on these steels were discussed in a paper by C. B. Voldrich, "Cold Cracking in the Heat-Affected Zone,"[2] which showed that the tendency to crack may vary widely in steels of similar chemical analysis. This is illustrated in Fig. 1 from the above paper which compares the extent of underbead weld cracking with the carbon equivalent of the steel. The carbon and manganese contents of these steels are shown in Table 1.

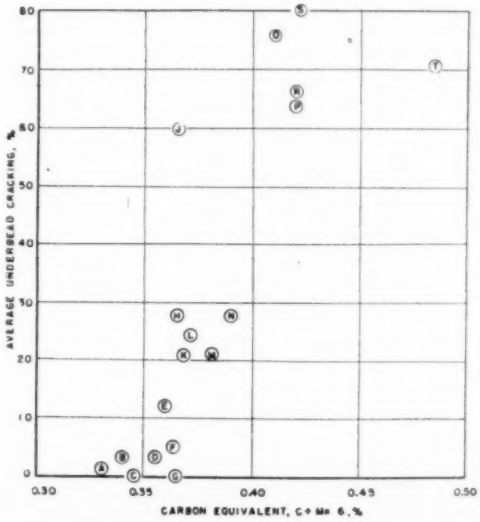

Fig. 1 Relation between crack sensitivity and carbon equivalent of high-tensile carbon-manganese steels

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From a study of the above steels, it was found that the abnormally high cracking was associated with manganese banding. This alloy banding is the result of segregation that occurs during the freezing of the ingot and persists through various stages of processing. The presence of alloy bands is revealed by pearlite banding in slowly cooled steels. During slow cooling, the low-manganese areas are the first to transform into ferrite, causing the carbon to diffuse into the high-alloy areas whose higher manganese content causes them to be the last to transform. Therefore, the occurrence of pearlite bands in these steels indicates the presence and location of alloy bands.

Table 1—Carbon and Manganese Contents and Carbon Equivalent of Steels Shown in Fig. 1

Steel	*Thickness, in.*	*C, %*	*Mn, %*	*C + Mn/6*
A	1	0.14	1.16	0.33
B	1	0.15	1.16	0.34
C	1	0.15	1.17	0.34
D	1	0.17	1.11	0.35
E	7/8	0.16	1.21	0.36
F	1	0.15	1.28	0.36
G	1	0.16	1.23	0.36
H	1	0.17	1.17	0.36
J	1	0.15	1.29	0.36
K	1	0.17	1.19	0.37
L	7/8	0.16	1.27	0.37
M	1	0.17	1.27	0.38
N	7/8	0.18	1.25	0.39
O	7/8	0.17	1.44	0.41
P	7/8	0.19	1.38	0.42
R	1	0.17	1.50	0.42
S	1	0.19	1.39	0.42
T	1	0.23	1.53	0.49

In studying the effect of segregation, it was found that the detrimental effects of banding could be overcome by homogenizing the plates at sufficiently high temperatures (2300 to 2350° F.), the time cycle depending upon the degree of banding and the thickness of the bands. Simple annealing of the hot-rolled plate was found to increase the cracking because of the tendency to concentrate the carbon in the high-alloy areas. Quenching followed by tempering did not have much influence upon the extent of cracking.

EXPERIMENTAL PROCEDURE

Following the above work, a study was made of low-alloy, high-tensile strength steels, the principal object being to develop a hot-rolled steel suitable for welded structures having the highest yield strength in medium heavy plates commensurate with good weldability and notch-bar impact strength. While the term weldability is usually cloaked in considerable mystery, satisfactory weldability for the above grade of steel can be defined simply as being suitable for metal-arc welding by the methods commonly used without the necessity of preheat to prevent underbead cracking. For the structures normally fabricated, any sound steel with the above qualification and made in accordance with accepted steelmaking practices, displays sufficient strength and ductility in the heat-affected zone to perform its normal functions satisfactorily, provided there are no defects, such as weld cracks, present to act as stress raisers and prevent the ductility from being realized.

It has been demonstrated that the design of the structure can be expected to overshadow the influence of steel quality with respect to the behavior of the structure under load, as was illustrated in the case of the Liberty ship hatch corner. On the other hand, however, if cold cracks occur in the heat-affected area, the structure is initially damaged and subsequent difficulty may be experienced. It is obvious, therefore, that the principal criterion of weldability for this grade of steel is that it be capable of being welded without underbead cracking by methods normally used in production, which excludes the use of preheat in this case.

Properties of Fully Hardened Steel. There has been considerable misapprehension concerning the properties of the hard structure in the heat-affected zone, it being assumed that martensite is inherently brittle and that this lack of ductility is the most likely cause of failure. Although relatively hard, the martensite or structure resulting from the drastic quenching of carbon-manganese or manganese-molybdenum steels and similar types that might be used for structural purposes is not normally brittle. In order to demonstrate that these quenched structures are ductile, both tensile and impact tests were made using water-quenched and untempered specimens from two commercial heats, Steels 23 and 26. The chemical analysis of these two steels is shown in Table 2.

Table 2—Chemical Analysis of Steels Used to Study the Properties of Fully Hardened Steel

Steel No.	*Chemical composition, %*					
	C	*Mn*	*P*	*S*	*Si*	*Mo*
23	0.19	1.46	0.020	0.018	0.25	0.37
26	0.14	1.44	0.013	0.027	0.25	0.48

After water quenching from 1650° F., the threaded-end tensile specimens were ground under water from 0.530 to 0.500 in. in diameter with a 2-in. parallel section tapered at both ends. To study the effect of even more drastic quenching, a second set of specimens was machined to 0.249 in. in diameter, water quenched from 1650° F., and tested in that condition and size.

The data from the above quenched specimens are shown in Table 3 together with the tensile data for the hot-rolled steel. These data show that with a tensile strength of over 210,000 psi. the reduction in area of the fully quenched steel (Steel No. 23) was approximately 50% when using the 0.500-in. specimen and 47% for the small specimen. These values compare favorably with the reduction in area of the hot-rolled steel which was approximately 56%. The elongation in 2 in. was 15 to 16% in the quenched bars as compared with 22 to 24% in the hot-rolled steel.

The Charpy notched-bar impact specimens were prepared by water quenching from 1650° F., after which

they were notched by grinding under water, the standard Izod-V notch being used. The results obtained from these specimens are shown in Table 4. The data show that these fully hardened steels are far from being brittle but have good notched-bar impact resistance at temperatures as low as −75° F., Steel No. 26 displaying 16 to 24 ft.-lb., and Steel No. 23, 11 to 25 ft.-lb., at this low temperature, as compared with 39 to 41 ft.-lb. and 25 to 29 ft.-lb. at +75° F., respectively, for the two steels.

Table 3—Tensile Data from Hot-Rolled and Water-Quenched Untempered Manganese-Molybdenum Steels

Steel No.	*Condition of steel*	*Specimen diameter, in.*	*Elongation in 2 in., %*	*Reduction of area, %*	*Yield strength, psi.**	*Tensile strength, psi.*	*Brinell hardness No.*
23	Hot-rolled	0.505	22.5	56.5	70,500	101,200	202
26	Hot-rolled	0.505	24.0	61.5	68,700	102,500	207
23	Quenched	0.500	15.0	49.0	143,500	212,200	421
23	Quenched	0.500	15.5	52.0	146,500	212,200	..
26	Quenched	0.500	16.0	57.0	137,500	187,500	363
26	Quenched	0.500	16.0	58.0	136,700	184,300	..
23	Quenched	0.247	8.5	46.5	...	221,300	..
23	Quenched	0.247	8.5	48.5	...	219,700	..
26	Quenched	0.247	10.5	59.0	...	195,200	..
26	Quenched	0.247	11.0	59.0	..	196,200	..

* Yield strength from strain at 0.2% offset.

From the above tensile and impact data, it is obvious that these steels in the fully hardened state have considerable ductility and resistance to notched-bar impact. It has been shown, however, by Herres[3] that the ductility of fully hardened steels is decreased to a marked extent by the presence of hydrogen and that the tensile strength is erratically lowered. The impact properties, however, are not affected to the same extent. Fortunately, the ductility of low- and medium-carbon steels embrittled by hydrogen is rapidly recovered while standing at room temperature or by a stress-relieving treatment.

Table 4—Notch-Bar Impact Strength of Water-Quenched Manganese-Molybdenum Steels

	Impact strength, ft.-lb., Charpy at testing temperatures:					
Steel No.	*−75° F.*	*−40° F.*	*−5° F.*	*+40° F.*	*+75° F.*	*+210° F.*
23	11	11	15	23	25	33
23	11	13	18	25	25	34
23	12	13	18	25	27	34
23	25	24	18	30	29	35
26	16	21	22	36	39	40
26	17	21	24	37	39	43
26	21	23	25	37	40	43
26	24	23	28	42	41	45

NOTE: The above data were obtained from Charpy specimens with a V-type Izod notch, the notch being perpendicular to the plate surface. After water quenching from 1650° F., the specimens were notched under water.

Underbead Cracking Test. In the work on this project, the procedure used in making the underbead crack-sensitivity test was slightly altered as compared with the procedure originally described by Voldrich. In order to eliminate any effect of the decarburized surface, the 1 1/2-in. bead was deposited in a groove, 1/16 in. deep by 1/2 in. wide, cut in a 2 x 3 x 1-in. specimen as shown in Fig. 2. The use of the groove was the only departure from the original procedure, the bead being deposited with a 1/8-in. E6010 type electrode using a power input of 100 amp. at 24 to 26 v. and a travel speed of 10 in. per minute. Prior to welding, the specimens were stored at 0° F. and during welding and for 10 sec. afterwards were partially immersed in a liquid bath at 0° F. unless otherwise stated. Following removal from the bath, the specimens were held for 24 hr. at 60° F. and then tempered at 1100° F. for 1 hr. After sectioning and polishing, the specimens were magnafluxed to show the cracks, as shown in Fig. 3, and the total length of the cracks in

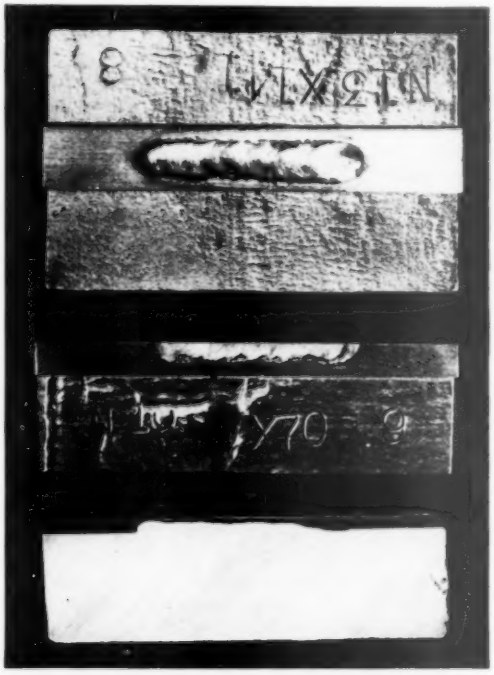

Fig. 2 Weld specimen for single-bead crack-sensitivity test
Showing longitudinal section used to expose underbead cracks

Fig. 3 Longitudinal section of weld specimen showing underbead crack

any one specimen determined and expressed as a percentage of the bead length. In most of the work, 10 duplicate specimens were welded for each steel tested and the average cracking value used. Although the extent of cracking varied considerably in different specimens, the average of 10 specimens was found to be reproducible within about 5 to 10%.

While the above description of the cracking test tends to imply that the phenomenon of underbead cracking is relatively simple, this is by no means the case. For example, it was shown by Voldrich[2] that the extent of underbead cracking increased slightly in most of the carbon-manganese steels studied, as the initial specimen temperature was increased from 0 to 120° F. followed by a sharp decrease at 200° F. More recently this trend has been observed on other steels in a more pronounced degree. It was also noted that increasing the electrode size and power input, which increased the heat input, sometimes increased the amount of underbead cracking. While these observations are contrary to orthodox opinion, it is believed they are not at variance with the basic principle involved. It is hoped that current work which is beyond the scope of this paper, will lead to a better understanding of the factors controlling underbead cracking.

Electrode Coatings. To show the effect of the electrode coating, underbead weld-cracking tests were made using three different types of electrodes with coatings which varied widely in hydrogen content. For this purpose, a hot-rolled commercial steel was selected (Steel No. 39, 0.19% C, 1.43% Mn and 0.33% Mo) which was prone to crack. Ten specimens were welded with each type of electrode, and the summary of the results is shown in Table 5.

Table 5—The Effect of the Electrode Coating Upon Underbead Weld Cracking in Steel 39

Type electrode	*Coating*	*Hydrogen content of coating*	*Underbead cracking, %**
E6010	Cellulosic	High	78
E6015	Lime	Low	0
E6020	Mineral	? (see text)	20

* Average of 10 specimens. See Table 1 in Appendix for complete data. Tables containing data of tensile and cracking tests on which the conclusions of this paper are based, are in an appendix which has been omitted from publication because of lack of available space. These data will be furnished in mimeograph form upon request.

The data in Table 5 show the influence of the electrode coating upon the extent of underbead cracking. Welding with the cellulosic-coated E6010 type electrode, which develops an arc atmosphere high in hydrogen, produced 78% cracking as compared to no cracking when the low-hydrogen, lime-coated E6015 type electrode was used.

While the use of the E6020 type electrode results in considerably less cracking, as compared with the E6010, the explanation for this difference is not too obvious since the arc atmosphere of the E6020 is relatively high in hydrogen; however the volume of gas generated per inch of electrode consumed is considerably less. As previously pointed out by Voldrich, additional study will be necessary in order to obtain a better understanding of the difference in behavior of these two electrodes.

Thus, it can be shown that certain types of electrode coatings will prevent underbead cracking, and efforts are being made to perfect such an electrode which will be universally acceptable for all types of work. Considerable progress has been made, and the realization of this goal would solve the underbead cracking problem very well. Since the object of the present work was to study the metallurgical factors influencing underbead cracking, an E6010 type of electrode, which produces extensive cracking, was selected.

Influence of Homogenizing on Underbead Cracking. While it was found that underbead cracking in hot-rolled plate could be decreased to a marked extent by a severe homogenizing treatment, such as heating 1-in. carbon-manganese plate to 2350° F. for 1 hr., this type of a treatment obviously could not be used commercially because of excessive scaling and warping. These difficulties could, however, be overcome if the homogenizing could be carried out in the slab prior to rolling into plate. In order to determine the effectiveness of such a procedure, 6-in.-thick slabs from a commercial heat (Steel No. 23) were homogenized for 2½, 5 and 10 hr. at 2350° F. in a standard ingot-soaking pit prior to rolling into 1-in. plate. The chemical analysis and the results of underbead cracking tests made on plate from the homogenized slabs are shown in Table 6. This Table also includes the results of underbead cracking tests made on regular hot-rolled plate from Steel 23 after the plate was homogenized at 2350° F. for various lengths of time under conditions precluding decarburization and scaling.

From Table 6 it will be noted that homogenizing the slabs at 2350° F. for periods of time extending up to 10 hr. did not reduce the cracking in the hot-rolled plate. When the plate was homogenized, however, at 2350° F. for only 10 min., followed by normalizing at 1600° F., the cracking was reduced from 78 to 35%, while homogenizing for 5 hrs. reduced the cracking to 14%.

From the above results, it appears that the time required to obtain sufficient diffusion of the high-alloy areas in the coarse slab structure to reduce cracking would be entirely too long for practical purposes. The fact that cracking can be decreased in the plate by ho-

Table 6—Chemical Analysis and Data on Homogenized Slabs and Plates from Steel 23

Steel No.	Chemical composition, % C	Mn	P	S	Si	Mo
23	0.19	1.46	0.020	0.018	0.25	0.37

Steel No.		Homogenizing time, hr.*	Underbead weld cracking, %†
23	Slab	0 (direct-rolled)	79
23	Slab	2½	81
23	Slab	5	80
23	Slab	10	79
23	Plate	0 (as-rolled)	78
23	Plate	¼	35
23	Plate	1	28
23	Plate	3	30
23	Plate	5	14

* Homogenized at 2350° F.
† See Table 2 in Appendix for complete data. See reference under Table 5.

mogenizing illustrates the influence of alloy segregation upon underbead cracking.

A comparison was made of the hardness developed in the heat-affected zones of hot-rolled and homogenized-normalized plate. These surveys were made on specimens prepared in the same manner as the underbead crack-sensitivity test specimens with the exception that the 1100° F. tempering treatment was omitted. After sectioning, hardness readings were taken at intervals of 0.005 in. across the hard zone. The data in Table 7 show that the maximum hardness developed under the weld bead in hot-rolled and in homogenized-normalized plate from Steel X-9 is essentially the same, although the underbead cracking differs widely, being 59 and 9%, respectively. These results have been confirmed by similar data from numerous steels. This indicates that hardness is not the controlling factor in establishing the weld crack sensitivity.

Influence of the Individual Alloys

In order to determine the relative influence of the common alloying elements upon underbead cracking and the yield strength, a study was made of a series of laboratory heats in which the following elements were varied through the range indicated: Group 1 heats, carbon 0.17 to 0.32%; group 2 heats, manganese 0.93 to 1.51%; group 3 heats, silicon 0.41 to 0.92%; group 4 heats, molybdenum 0.10 to 0.43%; group 5 heats, vanadium 0.04 to 0.29%; group 6 heats, chromium 0.28 to 1.00%; group 7 heats, titanium 0 to 0.38; group 8 heats, standard composition.

The standard composition chosen for comparison purposes was 0.21% carbon, 1.35% manganese, 0.28% silicon and 0.015% titanium with an addition of 0.4 lb. per ton of aluminum. This composition was selected because previous experience indicated that laboratory heats of the above analysis cracked well within the limits of the crack-sensitivity test conditions used for the commercial steels. The indications are that laboratory heats cast into small ingots are somewhat less crack sensitive than steel of a similar analysis from commercial ingots.

The chemical analyses of the 32 laboratory heats are listed in Table 8. These steels were processed by forging the 6⅝-in.-sq. ingots at 2200 to 2300° F. into 2- by 5-in. slabs. Following reheating to 2200° F., the slabs were hot rolled to 1-in. plate in six passes with the finishing temperature being approximately 1750° F. The plates were stood on edge and allowed to air cool as in normalizing. All tests were made on the plate in the hot-rolled condition unless otherwise stated.

Influence of Chemical Analysis Upon Underbead Cracking and the Yield Strength. The results of the underbead crack-sensitivity tests together with the yield strengths for the seven groups of steels are shown graphically in Figs. 4 to 10, inclusive, and the complete data are shown in Tables 3 and 4 of the Appendix. The single-bead cracking tests were made as previously described, with each of the data points in the above figures being the average of ten tests. The yield strength was determined from longitudinal 0.505-in. specimens using the load at 0.2% offset as indicated on the stress-strain curve.

A comparison of the above figures shows that carbon and manganese, especially carbon, have a pronounced influence upon underbead cracking, the cracking increasing rapidly as the carbon or manganese content is raised. An increase in the silicon content from about

Table 7—Hardness of the Heat-Affected Zone Under the Weld Bead in Hot-Rolled and Homogenized-Normalized Steels

Steel No.		Specimen No.	Weld metal	Vickers hardness — Heat-affected zone										Base metal
X-9	Hot-rolled	1	283	378	368	467	*498*	426	413	401	348	339	330	197
X-9		2	297	348	439	453	453	*467*	439	426	413	313	339	197
X-9	Underbead cracking, 59%	3	305	358	426	467	467	*482*	*482*	453	*482*	378	378	224
X-9		4	305	368	*467*	439	*467*	426	439	401	348	330	378	205
X-9	Homogenized and normalized	1	305	439	*482*	453	426	426	390	368	313	321	305	205
X-9		2	290	401	413	*413*	368	348	368	358	321	297	283	205
X-9	Underbead cracking, 9%	3	263	413	*515*	467	426	413	413	368	358	313	297	189
X-9		4	283	453	467	426	453	*467*	426	401	358	330	330	197

Steel No.	Chemical composition, % C	Mn	P	S	Si	Ti
X-9	0.21	1.51	0.023	0.018	0.29	0.011

0.20% to about 0.90%, however, resulted in only a small increase in the cracking, but there was no significant gain in yield strength.

The addition of vanadium and molybdenum, up to approximately 0.30 and 0.40%, respectively, resulted in no significant increase in underbead cracking, but was accompanied by an increase in yield strength of approximately 25,000 psi. It will be noted that the gain in yield strength resulting from increasing the carbon from 0.17 to 0.32% was only about 10,000 psi., while the cracking increased from approximately 20 to 100%.

Little advantage appeared in these tests from adding chromium since the yield strength was not increased appreciably, even though additions up to 1% were not detrimental to the underbead crack sensitivity. The addition of titanium produced no appreciable effect upon either the yield strength or crack sensitivity, as is indicated in Fig. 10.

The Effect of Aluminum Deoxidation. While investigating the influence of deoxidation practices upon the notched-bar impact properties, it was noted that the aluminum content appeared to affect the underbead weld cracking of the steel. In order to determine if the aluminum content resulting from deoxidation was an important factor with respect to weld cracking, a series of six heats were made with aluminum additions of 0, 1/4, 1/2, 1, 2 and 5 lb. per ton. The chemical analysis of these heats, together with the standard composition, is shown in Table 9. These heats were cast in 8- by 8-in. molds and rolled directly to 1-in. plate on a small commercial mill. All tests were made on the plate in the hot-rolled condition.

The results of the underbead cracking tests are shown in Fig. 11, and other pertinent data including the yield strength are shown in Table 10. From Fig. 11, it appears that the aluminum content may have a marked influence upon the weld crack sensitivity of the

Table 8—Chemical Analysis of Laboratory Heats Used to Study the Influence of Various Alloys

Heat No.	*C*	*Mn*	*P*	*S*	*Si*	*Ti*	*Mo*	*V*	*Cr*
				Group 1					
X-1	0.17	1.36	0.023	0.024	0.31	0.014	..	..	..
X-2	0.20	1.30	0.021	0.023	0.25	0.001	..	..	..
X-3	0.25	1.36	0.022	0.023	0.29	0.014	..	..	..
X-4	0.28	1.42	0.022	0.020	0.22	0.014	..	..	..
X-5	0.32	1.26	0.022	0.020	0.22	0.013	..	..	..
				Group 2					
X-6	0.21	0.93	0.021	0.022	0.27	0.010	..	..	..
X-7	0.19	1.22	0.023	0.018	0.28	0.011	..	..	..
X-8	0.22	1.37	0.023	0.018	0.29	0.012	..	..	..
X-9	0.21	1.51	0.023	0.018	0.29	0.011	..	..	..
				Group 3					
X-10	0.21	1.30	0.025	0.018	0.41	0.012	..	..	..
X-11	0.21	1.37	0.024	0.019	0.55	0.012	..	..	..
X-12	0.19	1.39	0.023	0.018	0.79	0.011	..	..	..
X-13	0.20	1.31	0.024	0.019	0.92	0.010	..	..	..
				Group 4					
X-14	0.22	1.45	0.023	0.019	0.30	0.025	0.10	..	..
X-15	0.21	1.49	0.020	0.020	0.35	0.012	0.12	..	..
X-16	0.23	1.29	0.023	0.022	0.28	0.012	0.24	..	..
X-17	0.23	1.32	0.020	0.020	0.30	0.012	0.32	..	..
X-18	0.24	1.37	0.023	0.020	0.29	0.014	0.43	..	..
				Group 5					
X-19	0.21	1.27	0.020	0.019	0.32	0.013	..	0.04	
X-20	0.20	1.30	0.021	0.020	0.30	0.016	..	0.08	
X-21	0.26	1.29	0.020	0.019	0.30	0.014	..	0.19	..
X-22	0.21	1.28	0.020	0.020	0.29	0.018	..	0.29	..
				Group 6					
X-59	0.20	1.37	0.025	0.026	0.32	0.014	..	..	0.28
X-60	0.20	1.33	0.024	0.030	0.33	0.012	..	..	0.52
X-61	0.21	1.36	0.024	0.026	0.34	0.012	..	..	0.78
X-62	0.22	1.30	0.024	0.025	0.31	0.015	..	..	1.00
				Group 7					
X-41	0.23	1.36	0.021	0.027	0.24	Nil	..	..	..
X-42	0.22	1.33	0.021	0.028	0.24	0.037	..	..	..
X-43	0.22	1.36	0.023	0.025	0.20	Nil	..	..	..
X-44	0.22	1.36	0.021	0.024	0.20	0.038	..	..	..
				Group 8					
X-45	0.21	1.35	0.021	0.030	0.27	0.015	..	..	
X-46	0.22	1.35	0.023	0.032	0.28	0.015	..	..	..

NOTE: All of the above heats were deoxidized with an addition of 0.4 lb. of aluminum per ton.

steel though, from other evidence, it appears that this effect depends on other factors as well. A small or medium amount of aluminum appears to be the most detrimental, indicating that the aluminum should either be omitted or added in a large amount to minimize weld cracking.

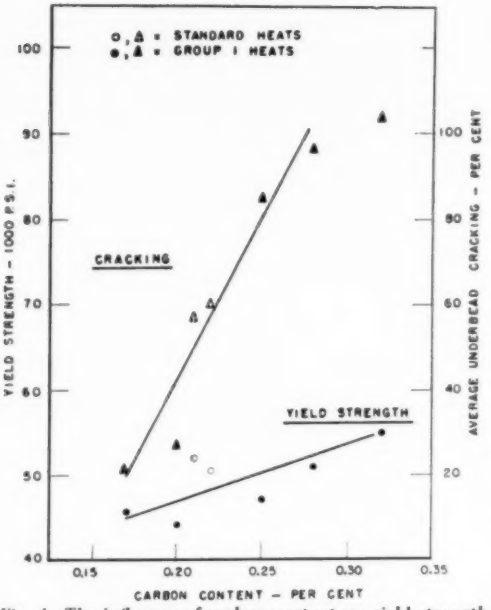
o, Δ = STANDARD HEATS
●, ▲ = GROUP 1 HEATS
CRACKING
YIELD STRENGTH
YIELD STRENGTH - 1000 P.S.I.
AVERAGE UNDERBEAD CRACKING - PER CENT
CARBON CONTENT - PER CENT

Fig. 4 The influence of carbon content on yield strength and underbead cracking

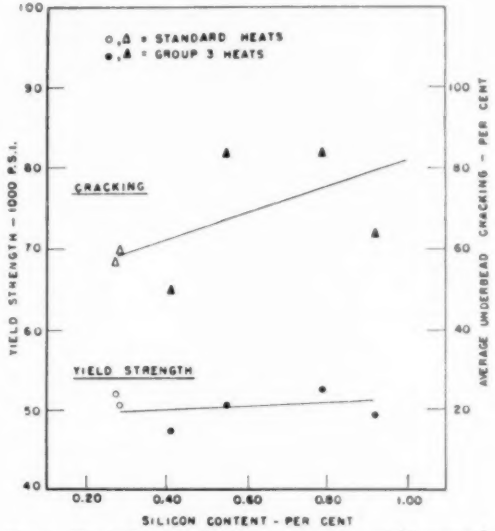
o, Δ = STANDARD HEATS
●, ▲ = GROUP 3 HEATS
CRACKING
YIELD STRENGTH
YIELD STRENGTH - 1000 P.S.I.
AVERAGE UNDERBEAD CRACKING - PER CENT
SILICON CONTENT - PER CENT

Fig. 6 The influence of silicon content on yield strength and underbead cracking

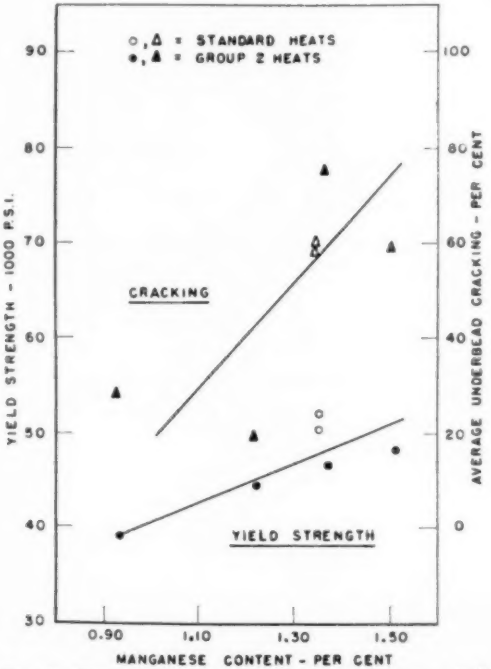
o, Δ = STANDARD HEATS
●, ▲ = GROUP 2 HEATS
CRACKING
YIELD STRENGTH
YIELD STRENGTH - 1000 P.S.I.
AVERAGE UNDERBEAD CRACKING - PER CENT
MANGANESE CONTENT - PER CENT

Fig. 5 The influence of manganese content on yield strength and underbead cracking

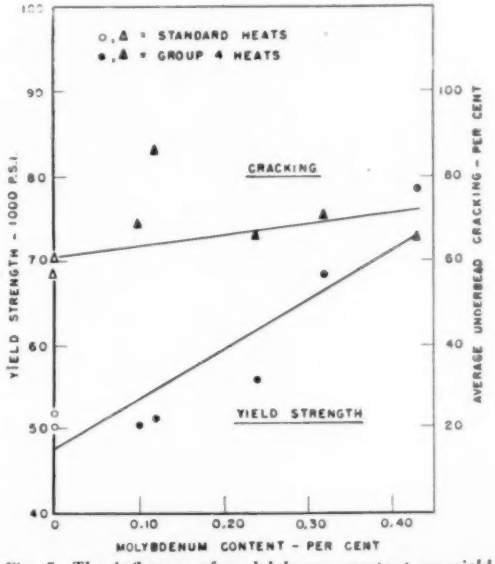
o, Δ = STANDARD HEATS
●, ▲ = GROUP 4 HEATS
CRACKING
YIELD STRENGTH
YIELD STRENGTH - 1000 P.S.I.
AVERAGE UNDERBEAD CRACKING - PER CENT
MOLYBDENUM CONTENT - PER CENT

Fig. 7 The influence of molybdenum content on yield strength and underbead cracking

Table 9—Chemical Analysis of Steels Used to Study the Influence of Aluminum Content

Heat No.	*C*	*Mn*	*P*	*S*	*Si*	*Ti*	*Al**	*Aluminum added, lb. per ton*
X-23	0.20	1.25	0.021	0.022	0.27	0.007	Nil	0
X-24	0.23	1.36	0.019	0.021	0.29	0.006	<0.005	0.25
X-25	0.22	1.24	0.020	0.020	0.27	0.013	<0.005	0.5
X-26	0.22	1.31	0.021	0.021	0.27	0.016	0.029	1
X-27	0.20	1.29	0.018	0.020	0.31	0.015	0.064	2
X-28	0.22	1.26	0.019	0.020	0.27	0.015	0.180	5
X-45†	0.21	1.35	0.021	0.030	0.27	0.015	0.003	0.4
X-46†	0.22	1.35	0.023	0.032	0.28	0.015	0.003	0.4

* Acid-soluble aluminum content.
† Heats X-45 and X-46 are the standard composition steels.

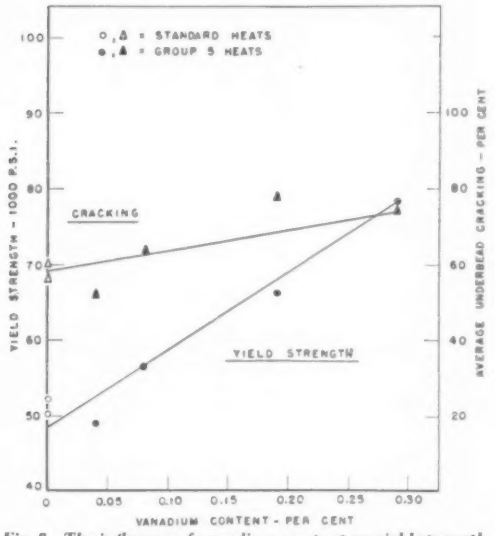
○, △ = STANDARD HEATS
●, ▲ = GROUP 5 HEATS
CRACKING
YIELD STRENGTH
YIELD STRENGTH - 1000 P.S.I.
AVERAGE UNDERBEAD CRACKING - PER CENT
VANADIUM CONTENT - PER CENT

Fig. 8 The influence of vanadium content on yield strength and underbead cracking

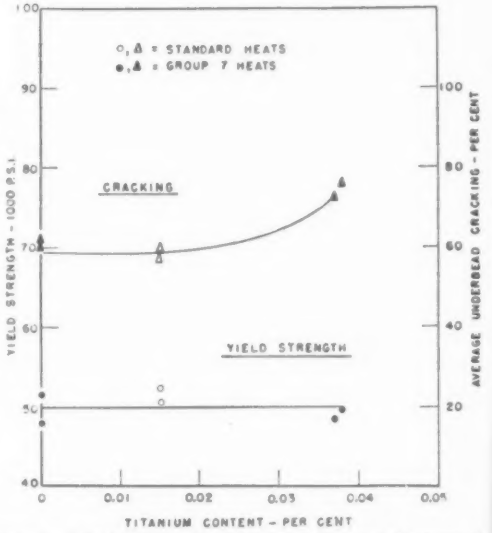
○, △ = STANDARD HEATS
●, ▲ = GROUP 7 HEATS
CRACKING
YIELD STRENGTH
YIELD STRENGTH - 1000 P.S.I.
AVERAGE UNDERBEAD CRACKING - PER CENT
TITANIUM CONTENT - PER CENT

Fig. 10 The influence of titanium content on yield strength and underbead cracking

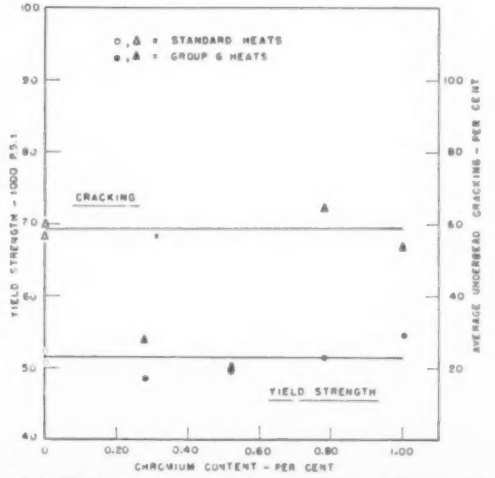
○, △ = STANDARD HEATS
●, ▲ = GROUP 6 HEATS
CRACKING
YIELD STRENGTH
YIELD STRENGTH - 1000 P.S.I.
AVERAGE UNDERBEAD CRACKING - PER CENT
CHROMIUM CONTENT - PER CENT

Fig. 9 The influence of chromium content on yield strength and underbead cracking

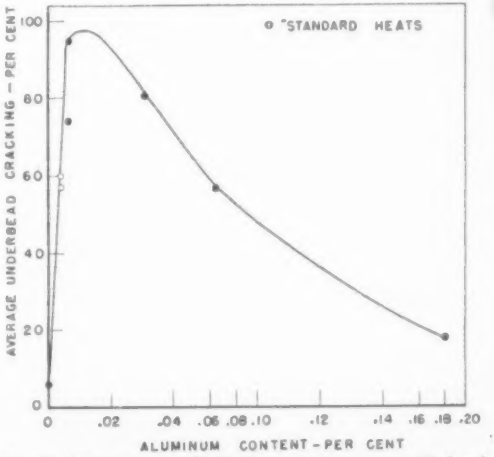

Fig. 11 The effect of aluminum content upon underbead weld crack sensitivity

Table 10—Data from Heats Made for Studying the Influence of Aluminum Additions

Heat No.	*C*	*Mn*	*Aluminum added, lb. per ton*	*Yield strength, psi.*	*Underbead weld cracking, %*
X-23	0.20	1.25	0	47,500	6
X-24	0.23	1.36	0.25	50,880	95
X-25	0.22	1.24	0.5	47,750	74
X-26	0.22	1.31	1	49,630	81
X-27	0.20	1.29	2	48,250	57
X-28	0.22	1.26	5	48,380	17
X-45	0.21	1.35	0.4	52,100	57
X-46	0.22	1.35	0.4	50,750	60

NOTE: See Tables 5 and 6 of the Appendix for complete tensile and underbead cracking data. See reference under Table 5.

Since the reason for the apparent influence of aluminum was not obvious and the data rather limited, a second group of heats were made to see if the above results could be verified. Three 450-lb. induction furnace heats were made, and each heat was poured into two ingots, the first ingot being cast without the use of aluminum, while the second ingot was poured from the remainder of the heat after being deoxidized with an addition of 0.5 lb. of aluminum per ton of steel. The $6^{3}/_{8}$-in. ingots were then processed into 1-in. plates by forging and rolling in the same manner as the first group of 32 heats.

From Table 11 it will be noted that the chemical analyses of these six ingots are quite similar with the exception of the manganese content, which varies from 1.13 to 1.40% and therefore must be taken into consideration.

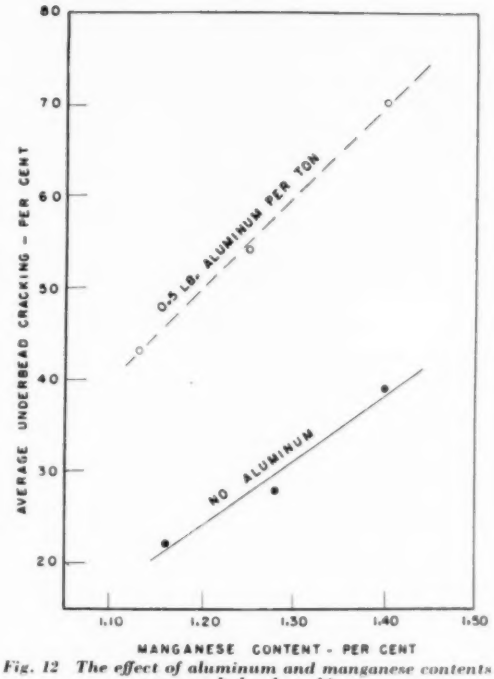

Fig. 12 The effect of aluminum and manganese contents upon underbead cracking

Data from heats X-29, X-31 and X-33. (See Table 7 in Appendix, also reference under Table 5 in this article)

Table 11—Chemical Analysis of Split Heats Made to Study the Effect of Aluminum

Heat No.	*Ingot No.*	*C*	*Mn*	*P*	*S*	*Si*	*Ti*	*Al*	*Aluminum added, lb. per ton*
X-29	1	0.21	1.16	0.023	0.024	0.20	0.008	Nil	0
X-29-A	2	0.21	1.13	0.019	0.025	0.17	0.008	0.005	0.5
X-31	1	0.22	1.28	0.023	0.027	0.26	0.008	Nil	0
X-31-A	2	0.21	1.25	0.023	0.026	0.24	0.006	0.005	0.5
X-33	1	0.21	1.40	0.022	0.025	0.26	0.009	Nil	0
X-33-A	2	0.21	1.40	0.022	0.024	0.24	0.007	0.005	0.5

The data from the crack-sensitivity tests in Fig. 12 confirm the previous results since they definitely show that the crack sensitivity was increased to a marked extent by the addition of $^{1}/_{2}$ lb. of aluminum per ton as compared to a similar steel with no aluminum. The influence of manganese content is also well illustrated in the above figure.

Influence of Chemical Analysis Upon the Notched-Bar Impact Strength. The effects of the various elements included in this study upon the notched-bar impact strength (Vee-notch Charpy) when tested at 75° F. are shown in Fig. 13 to 19, inclusive. These figures illustrate how the notched-bar impact strength of the hot-rolled plate decreases as the carbon, silicon, molybdenum, vanadium and chromium contents are increased.

In the case of manganese and titanium, the scatter band is rather wide, and the data do not appear to follow a definite pattern, so it is difficult to draw any conclusion from the data other than that these elements do not appear to be especially detrimental in the range investigated.

When tested at room temperature, the aluminum content had little influence upon the notched-bar strength. The expected effect, however, was found when tested at lower temperatures, the intermediate aluminum contents (0.06 to 0.12% residual Al) producing the highest notched-bar strength at −40° F. as shown in Fig. 20.

Optimum Chemical Analysis

From this study of the influence of carbon, manganese, silicon, chromium, molybdenum, vanadium

and aluminum contents upon the behavior of a low-alloy high-tensile strength hot-rolled steel, it is obvious that both the carbon and manganese contents, especially the carbon, must be carefully limited in order to minimize the underbead cracking. With the carbon and manganese contents lowered to obtain the desired weldability, the required yield strength must be obtained by the addition of such alloys as molybdenum or vanadium which do not increase the underbead cracking.

Low-Carbon-Manganese-Vanadium Steels with No Aluminum. Since the addition of small or medium

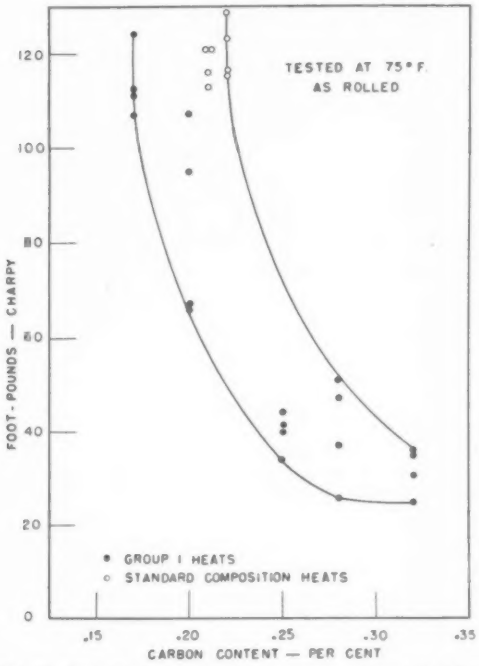

Fig. 13 The effect of carbon content upon the notched-bar impact strength at 75° F.

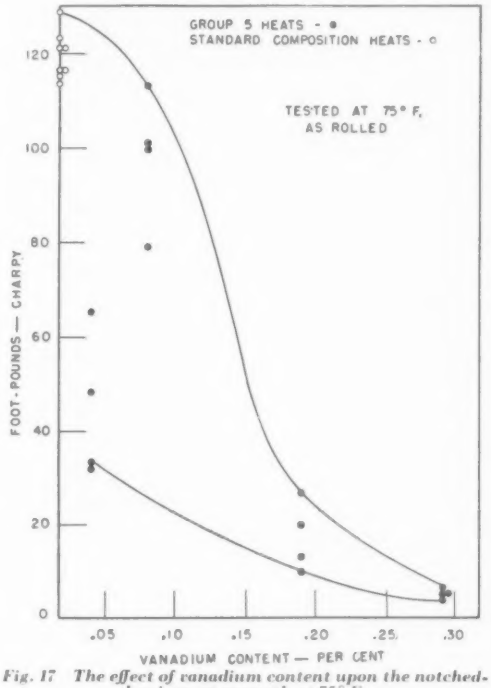

Fig. 17 The effect of vanadium content upon the notched-bar impact strength at 75° F.

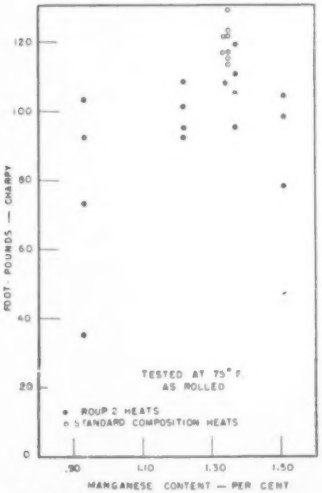

Fig. 14 The effect of manganese content upon the notched-bar impact strength at 75° F.

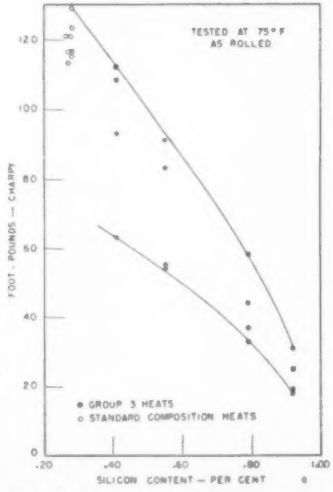

Fig. 15 The effect of silicon content upon the notched-bar impact strength at 75° F.

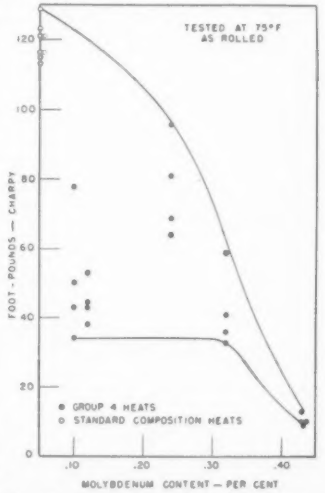

Fig. 16 The effect of molybdenum content upon the notched-bar impact strength at 75° F.

amounts of aluminum was found to increase the susceptibility to underbead cracking, the aluminum may be omitted. In order to ensure sound ingots the silicon content should then be not less than about 0.25 per cent.

In order to determine the physical properties and the accompanying level of underbead cracking that could

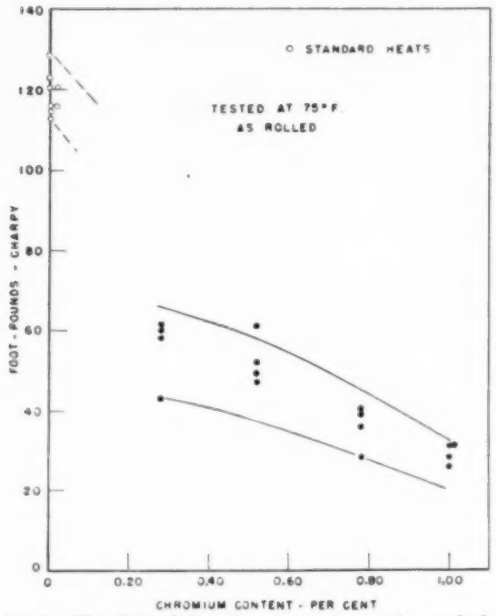

Fig. 18 The effect of chromium content upon the notched-bar impact strength at 75° F.

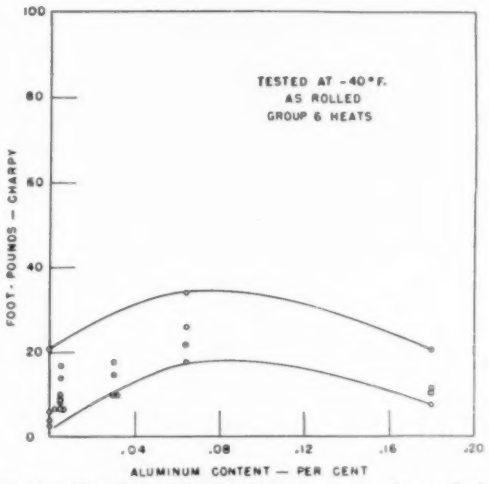

Fig. 20 The effect of aluminum content upon the notched-bar impact strength at −40° F.

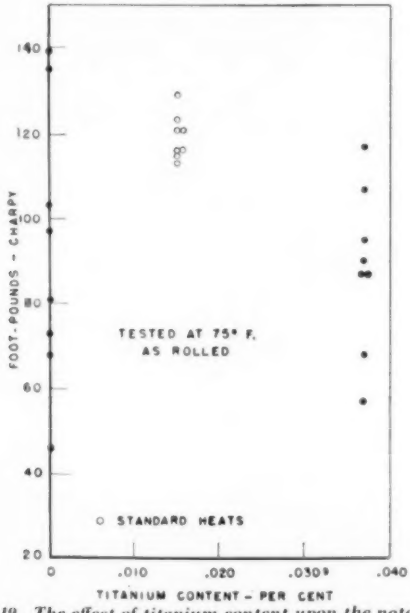

Fig. 19 The effect of titanium content upon the notched-bar impact strength at 75° F.

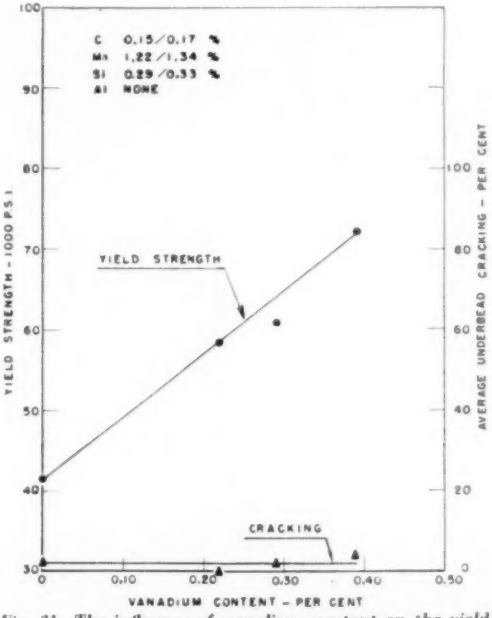

Fig. 21 The influence of vanadium content on the yield strength and underbead cracking of low-carbon steel

(See Tables 8 and 9 in the Appendix, also reference under Table 5 in this article)

be obtained by the above approach, a series of four laboratory induction furnace heats were made aiming at the following chemical analysis with vanadium contents of 0, 0.20, 0.30 and 0.40%: C, 0.16 max.; Mn, 1.20 max.; Si, 0.30; Ti, 0.015; Al, none; V, see text.

The chemical analysis of these four heats is shown in Table 12. It will be noted that the manganese content of three of the heats is 10 to 14 points higher than desired but that otherwise the analyses are in the desired range. The titanium recovery was erratic as would be expected when no aluminum is used. After processing the heats to 1-in. plate in the same manner as the other laboratory heats, they were tested in the hot-rolled condition.

The results of the underbead cracking tests and the yield strength of these steels are shown in Fig. 21 and Tables 8 and 9 of the Appendix. These data show that the susceptibility to underbead cracking can be reduced to an extremely low level by limiting the carbon content and omitting the aluminum while obtaining the desired yield strength by the addition of vanadium. By adding 0.39% vanadium to a 0.16% carbon steel with 1.30% manganese, and omitting the aluminum, a yield strength of 72,000 psi. was obtained from the 1-in. hot-rolled plate which cracked only 4%, indicating an extremely low tendency toward underbead cracking.

The notched-bar impact strength of the two low-carbon (0.16% max.) heats containing 0.22 and 0.39% vanadium tested at temperatures ranging from −75 to 210° F. is shown in Fig. 22. Although aided by the relatively low-carbon content, the Charpy strength of these vanadium steels is quite low when tested in the hot-rolled condition. It is obvious, however, that omitting the aluminum in order to lower the underbead cracking is not conducive to good notched-bar impact strength.

High Aluminum Vanadium-Molybdenum Steels. In order to determine if any advantage might be gained, especially in the notched-bar impact strength, by using a large addition of aluminum and a combination of vanadium and molybdenum as alloys to increase the strength, a series of four heats were made with a vanadium content of approximately 0.12% and the molybdenum ranging from 0.12 to 0.72%. Each heat was deoxidized with an addition of 4 lb. of aluminum per ton of steel. The chemical analyses of these steels are listed in Table 13.

These heats were forged and rolled into 1-in. plate in the manner previously described. A brief summary of the test results from the hot-rolled plate is shown in Table 14 and Fig. 23. These data again show that high yield strength hot-rolled steels can be produced, which display a very low tendency toward underbead cracking but have relatively low notched-bar impact strength. In this case, the use of a large aluminum addition and the combination of vanadium and molybdenum did not improve the impact strength to any appreciable extent.

From these results it appears that the combination of high yield (70,000 psi. minimum) and notched-bar impact strength, together with low sensitivity to underbead cracking, cannot be obtained from hot-rolled, 1-in. plate. It is necessary, therefore, to resort to some other scheme to obtain this combination of properties.

Table 12—Chemical Analysis of Low-Carbon Vanadium Steels with No Aluminum

Heat No.	*C*	*Mn*	*P*	*S*	*Si*	*Ti*	*V*	*Aluminum added*
972	0.17	1.22	0.018	0.018	0.29	0.005	Nil	None
X-38	0.16	1.30	0.017	0.043	0.29	0.005	0.22	None
X-39	0.15	1.34	0.013	0.041	0.30	0.025	0.29	None
X-40	0.16	1.32	0.012	0.040	0.33	0.025	0.39	None

Table 13—Chemical Analysis of Low-Carbon Vanadium-Molybdenum Heats Made with 4 Lb. of Aluminum per Ton

Heat No.	*C*	*Mn*	*P*	*S*	*Si*	*V*	*Mo*
X-48	0.15	1.28	0.016	0.027	0.31	0.12	0.12
X-50	0.14	1.30	0.020	0.027	0.28	0.12	0.32
X-52	0.15	1.31	0.020	0.029	0.32	0.13	0.49
X-54	0.13	1.28	0.018	0.031	0.29	0.13	0.72

Table 14—Summary of Data from Hot-Rolled Low-Carbon Vanadium-Molybdenum Heats Made with 4 Lb. of Aluminum per Ton

Heat No.	*C*	*Mn*	*Mo*	*Yield strength psi.*	*Reduction of area, %*	*Underbead weld cracking %*	*Charpy impact, V-notch, ft.-lb.* *Tested, −40° F.*	*Tested, 75° F.*
X-48	0.15	1.28	0.12	53,880	64.2	1	6–16	32–50
X-50	0.14	1.30	0.32	67,130	63.8	0	5–7	33–35
X-52	0.15	1.31	0.49	72,500	60.7	1	3–8	14–19
X-54	0.13	1.28	0.72	75,000	64.1	0	3–4	9–11

NOTE: (1) All the above tests were made on 1-in plate. (2) Complete tensile and cracking data in Table 10 and 11 of the Appendix. See reference under Table 5.

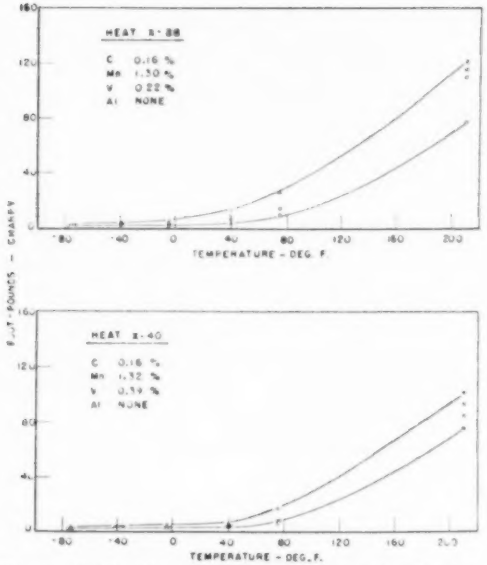

Fig. 22 Notched-bar impact strength of hot-rolled low-carbon manganese-vanadium steel with aluminum omitted

Table 15—Chemical Analysis and Physical Properties of Hot-Rolled and Quenched and Tempered 1-In. Plate from Heat 3

Steel No.	Chemical composition, % C	Mn	P	S	Si	Ti	V	Al*
30	0.18	1.25	0.023	0.026	0.28	0.007	0.004	0.016

Steel No.	Condition of plate	Tensile properties† Elongation in 2 in., %	Reduction of area, %	Yield strength, psi.	Tensile strength, psi.
30	Hot-rolled	34.6	64.9	50,350	76,150
30	Quenched and tempered	23.4	62.8	90,880	108,200

Steel No.	Condition of plate	Notched-bar impact strength — Testing temperature, ° F. −84	−32	−4	Impact values, ft.-lb. 33	76
30	Hot-rolled	6	11	25	31	79
30	Hot-rolled	6	21	26	52	57
30	Hot-rolled	6	7	26	52	76
30	Hot-rolled	5	18	24	76	58
30	Quenched and tempered	7	22	64	82	71
30	Quenched and tempered	8	25	70	76	67
30	Quenched and tempered	12	18	40	67	67
30	Quenched and tempered	12	30	38	64	75

(Charpy specimens with Izod V-type notch)

* Acid soluble.
† 0.505-in. tensile specimens.

Heat-Treated Plate

Since previous work indicated that the crack sensitivity of hot-rolled plate was not altered appreciably by quenching and tempering, the use of such a heat treatment appeared to be a practical method of improving the notched-bar impact strength and still retaining the other desired properties.

Carbon-Manganese Steel. In order to obtain more information, especially about the welding characteristics of quenched and tempered steel, 1-in. plate from a commercial heat with 0.18% carbon and 1.25% manganese (Steel No. 30) was water quenched from 1650° F. after being at temperature for 1 hr., followed by tempering at 1000° F. for 1 hr. The chemical analysis, tensile strength and notched-bar impact properties of Steel No. 30 are shown in Table 15. The tensile tests show that the above heat treatment developed a yield strength of 90,000 psi. and a notched-bar impact strength of 18 to 30 ft.-lb. Charpy (V-notch specimen) at −32° F. as compared with only 7 to 21 ft.-lb. for the hot-rolled steel tested under similar conditions. The underbead cracking tests showed that the quenched and tempered steel cracked 38% as compared with 28% for the hot-rolled plate. This difference is insignificant in view of the gain in tensile strength. (See Table 12 in Appendix.)

From the above results, it is obvious that the underbead cracking could be reduced and the notched-bar impact strength further improved by lowering both the carbon and manganese contents and still obtain a high strength, 75,000 to 85,000 psi. yield strength. To determine the results of lowering the carbon and manganese, a commercial plate steel was tested having a carbon content of 0.15% and 0.79% manganese, the steel being supplied by the producer in the form of $^3/_4$-in. quenched and tempered plate. The chemical analysis, heat treatment and tensile properties are shown in Table 16. It will be noted that the yield strength is in excess of 80,000 psi.

The twenty weld bead cracking tests made on specimens from this heat showed no evidence of underbead cracking. This might be expected as a result of the low carbon and manganese contents, while the high silicon

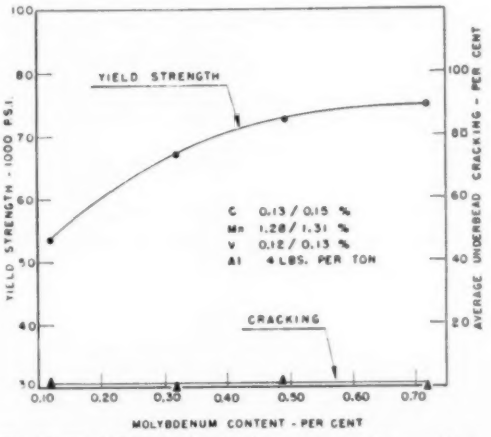
YIELD STRENGTH
C 0.13 / 0.15 %
Mn 1.28 / 1.31 %
V 0.12 / 0.13 %
Al 4 LBS. PER TON
CRACKING
YIELD STRENGTH - 1000 PSI
AVERAGE UNDERBEAD CRACKING - PER CENT
MOLYBDENUM CONTENT - PER CENT

Fig. 23 The influence of molybdenum content in vanadium-bearing low-carbon steel with high aluminum content

and small amounts of molybdenum, chromium and zirconium would not be considered as detrimental.

The results of notched-bar impact tests broken at temperatures ranging from −75 to 212° F. are shown in Fig. 24. These results were obtained from longitudinal Charpy specimens with an Izod V-notch cut perpendicular to the plate surface. At −75° F., the notched-bar impact strength was between 15 and 21 ft.-lb., and when tested at −40° F. was between 21 and 25 ft.-lb. These results can be considered satisfactory notch-bar properties. The indications are, however, that better impact strength might be obtained from this steel since some ferrite was found in the microstructure. Tests showed that the ferrite was the result of incomplete austenitizing previous to quenching.

Table 16—Chemical Analysis, Tensile Properties, and Heat Treatment of Quenched and Tempered 3/4-In. Commercial Plate

Steel No.	Chemical analysis, % C	Mn	P	S	Si	Mo	Cr	Zr	Al*
24	0.15	0.79	0.024	0.032	0.73	0.16	0.61	0.14	0.033

Tensile properties†	Elongation in 2 in., %	Reduction of area, %	Yield strength, psi.	Tensile strength, psi.
24	21.3	64.0	83,300	101,000
24	Heat Treatment Water quenched from 1650° F. Tempered at 1200° F.			

* Acid-soluble aluminum content.
† Tensile properties determined from 0.505-in. specimens. Complete tensile data in Table 13 of Appendix. See reference under Table 5.

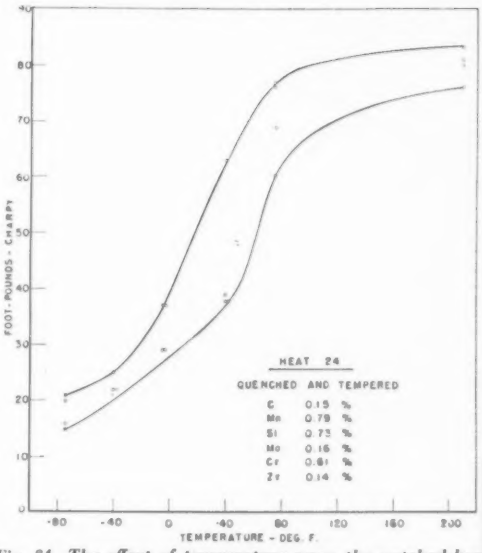

Fig. 24 The effect of temperature upon the notched-bar impact strength of quenched and tempered plate

Joint Efficiency of Welded Heat-Treated Plate

While high strength can be obtained from the quenched and tempered plate, the question arises concerning the influence of the heat-affected zone upon the strength of the plate following welding. To answer this question, tests were made to determine the tensile efficiency of welded butt joints in quenched and tempered plate. For this purpose, two commercial steels were used, Steel No. 24, which was previously described in Table 16, and Steel No. 40, a manganese-molybdenum steel. In this case, both steels were water quenched from 1600° F. and tempered at 1200° F.

The welds were made with 3/16-in. high-strength lime-coated electrodes (approximately an E9015). Each side of the double-V joint was welded in four passes as illustrated in Fig. 25, the temperature of the plate being allowed to drop to 200° F. between each pass. Tensile bars 1 1/4 in. wide were prepared as indicated in the Fig. 25. The data obtained from these tests are shown in Table 17.

The data in Table 17 indicate that the strength of the weld and heat-affected zone is equivalent to that of the base plate.

SUMMARY

It was found that fully hardened low-alloy steel with 0.15 to 0.20% carbon was not brittle but had consider-

Table 17—Data from Joint Efficiency Tests

Steel No.	Chemical composition, % C	Mn	Si	Mo	Cr	Zr	Description of specimen	Yield strength, psi.
24	0.15	0.79	0.73	0.16	0.62	0.14	3/4-in. plate, not welded	79,600
24							3/4-in. plate, welded reinforcement intact	78,500
24							3/4-in. plate, weld beads machined flush	78,400
40	0.14	1.24	0.24	0.43			1-in. plate, not welded	86,600
40							1-in. plate, welded reinforcement intact	82,800
40							1-in. plate, weld beads machined flush	84,100

NOTE: The fracture in all the specimens from Steel 24 occurred 2 to 3 in. from the weld. In Steel 40 the fractures were all approximately 1 1/2 in. outside the weld. See Table 14 of Appendix for complete tensile data. See reference under Table 5.

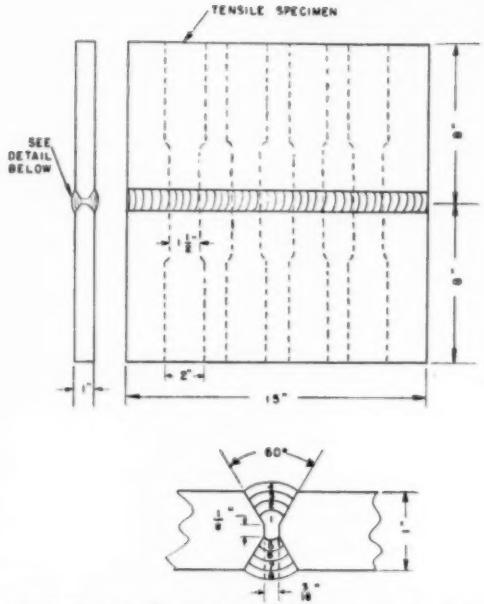

Fig. 25 Method of preparing tensile specimens for determining the joint efficiency of quenched and tempered butt-welded plate

able ductility and notched-bar impact strength. This, and evidence as given in Table 7, indicates that the occurrence of cracks in the hard heat-affected zone is not caused by high hardness and thermal stress alone. On the other hand, underbead cracking is held to be the result of highly localized aerostatic stresses set up by delayed release of hydrogen. This is further substantiated by the showing that underbead cracking is eliminated in an extremely crack-sensitive steel by using lime-coated electrodes of low hydrogen content. The use of these electrodes, however, is not yet universally acceptable for all types of work. For the present, then, it is desirable to produce a steel with low cracking tendency with the more common types of electrodes.

While the detrimental effect of alloy banding in hot-rolled steel can be reduced to a marked extent by a severe homogenizing treatment, this procedure is not yet practical because of the extremely long time that is required if the steel is homogenized in the slab prior to rolling into plate, and because of the excessive scaling and warping if homogenized as plate.

A study of the influence of carbon, manganese, silicon, molybdenum, vanadium, chromium, titanium and aluminum showed that increases in carbon and manganese content, especially carbon, were accompanied by a marked increase in cold cracking adjacent to weld beads. The addition of silicon or chromium up to approximately 1.0% had little effect upon underbead cracking but was of little value since the yield strength was not increased appreciably. The addition of titanium up to approximately 0.04% behaved in a similar manner.

The use of vanadium and molybdenum was found to increase the yield strength to a marked extent with no significant increase in underbead cracking.

The use of small or medium amounts of aluminum for deoxidation in the steelmaking practice was found to be quite detrimental with respect to underbead cracking, the cracking being reduced substantially by either omitting the aluminum or by using large additions, such as 4 lb. per ton.

By limiting the carbon and manganese contents to 0.13/0.15 and 1.30%, respectively, and adding approximately 0.12 vanadium and 0.50% molybdenum to obtain the desired strength, it was found that a yield strength in excess of 70,000 psi. could be obtained from 1-in. hot-rolled plate with an extremely low tendency toward underbead cracking. The notched-bar impact strength of this steel, however, was relatively low regardless of the aluminum content.

It was found that both high yield strength and notch-bar toughness, accompanied by low underbead cracking, could be obtained from quenched and tempered plate made from steel with limited carbon and manganese contents. The joint efficiency of this heat-treated plate when butt welded with a high-strength electrode was practically 100%.

ACKNOWLEDGMENT

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SILICON COPPER 943	99.75 Copper, .25 Silicon	1083	1981	Oxy-acetylene welding of copper, copper to steel.
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PHOSPHOR BRONZE 903	95.75 Copper, 4.00 Tin, .25 Phosphorus	1050	1922	Carbon arc welding of phosphor bronze and copper. Special applications to steel.
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